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Monterey, California. Naval Postgraduate School

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# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

OPTIMIZATION OF THREE DIMENSIONAL COMBINED  
TRUSS/FRAME STRUCTURES

by

Gregory L. Bender

October 1982

Thesis Advisor:

G.N. Vanderplaats

Approved for public release; distribution unlimited.

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displacement method is used for static analysis, and structure natural frequencies are calculated via the sub-space iteration method.

Flexibility is provided for expansion to other than tubular frame elements, and provisions are made for the future growth to panel and other types of structural elements.

Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.



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Optimization of Three Dimensional Combined  
Truss/Frame Structures

by

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Lieutenant, United States Navy  
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Submitted in partial fulfillment of the  
requirements for the degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

AND

MECHANICAL ENGINEER

from the

NAVAL POSTGRADUATE SCHOOL  
October 1982

---



## ABSTRACT

A finite element code is developed for analysis and design of three dimensional truss and frame structures. Structures are designed for minimum weight subject to constraints on: member stresses, Euler buckling, shell buckling, joint displacements and system natural frequencies. Structures are optimized with respect to member size and structure configuration.

The finite element code may be used for analysis only, or may be coupled to an optimizer of the user's choice. The displacement method is used for static analysis, and structure natural frequencies are calculated via the subspace iteration method.

Flexibility is provided for expansion to other than tubular frame elements, and provisions are made for the future growth to panel and other types of structural elements.

Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.





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## I. INTRODUCTION

The task of the Engineer is to provide the best solution to the customer's problem. Usually the "best" solution is the one that does the job with an adequate margin of safety, is aesthetically pleasing, and is economically feasible. The solution may be reached through various means, but efficient use of design tools, as well as efficient use of materials is important since both add to the overall cost of the product. Design optimization is one method that can be used to maximize the efficiency of a structure by minimizing its weight and, presumably, cost.

Optimization of structures has had continuing changes since its development in the early 1960's with an active area of research being elastic structures. The main goal is to design structural systems that efficiently perform specified purposes. Since most physical structures can be modeled by the finite element method, a computer program can be written to perform the necessary calculations to solve the problem.

The purpose of this research was to develop a finite element code that could be used to analyze a combined truss/frame structure and could be easily coupled to an optimizer; thus providing a useful tool for designing such structures



as, for example, ships' masts. This code expands the previous work by Fitzgerald [Ref. 1] on truss structures to the more general six degree-of-freedom truss/frame case.

The design problem considered in this study is the optimization of three-dimensional statically indeterminant combined truss-frame structures under varying load conditions and subject to a variety of constraints. The objective is to minimize the weight of the structure where the design variables are member sizes and joint coordinates. Constraints include: maximum normal stress; maximum joint displacements; minimum structure natural frequencies; Euler buckling; and in the case of the tubular frame elements, local or shell buckling.

In the present code, all gradient information is calculated by the finite difference method. Modification of the code to permit calculation of gradients analytically has been identified as a necessary future extension.

This document describes the use and capabilities of the finite element computer code to be coupled to an optimizer. The user's manual presented in Chapter V contains a simple design example in which the program is coupled to the CONMIN optimization code [Ref. 2]. Additionally, guidelines for coupling the code to an optimizer of the user's choice are presented.





Several examples demonstrating the program under a variety of conditions are presented. Conclusions and recommendations for future work are given.



## II. ANALYSIS

### A. INTRODUCTION

When the finite element method of analysis is used to design optimization, two objectives must be kept in mind. First, the number of analyses for the structure should be kept to a minimum. Second, the amount of gradient information required during the design process should be minimized to shorten run times and minimize computer storage requirements.

### B. STATIC ANALYSIS

Initial formulation of the problem must include approximate member areas in the case of truss elements, and for frame elements, characteristic dimensions (for tubular members: mean diameter and wall thickness); material properties (which may be different for each member); a set or sets of external loads; any non-structural attached masses; and specified joint support conditions.

The analysis for the stresses and deflections at the joints must satisfy the conditions of equilibrium of forces at the nodes and geometric conditions of compatibility of deformation. In this analysis the structure is assumed to behave in a linearly elastic fashion. The weight of an individual member is not inherently included as part of the



specified load conditions; but, as an option, half of the weight of each member may be applied at the member's end-points as an additional load in the negative Y-direction.

For this analysis, the following assumptions are made: truss and frame members are treated as discrete entities; truss elements have three translational degrees of freedom at each node and are treated as pin-connected; frame elements have three translational and three rotational degrees of freedom at each node and are treated as fixed-fixed beams; and loads and reactions are applied at the joints as shown in Figure 2.1.

The Displacement (Stiffness) method for finite element analysis [Ref. 3] is utilized where

$$\underline{\tilde{K}}\underline{y} = \underline{\tilde{F}} \quad (3.1)$$

and where  $\underline{\tilde{K}}$  is the global stiffness matrix,  $\underline{\tilde{F}}$  is the vector or vectors of applied loads, and  $\underline{y}$  is the vector or vectors of displacements. The method used herein is an extension of that described by Felix and Vanderplaats [Ref. 4]. By applying the constitutive stress-displacement relationships, stresses in the elements may be recovered.

### C. DYNAMIC ANALYSIS

When constraints on the system's natural frequencies are to be considered, the design process requires the solution of an eigenvalue problem. The sub-space iteration



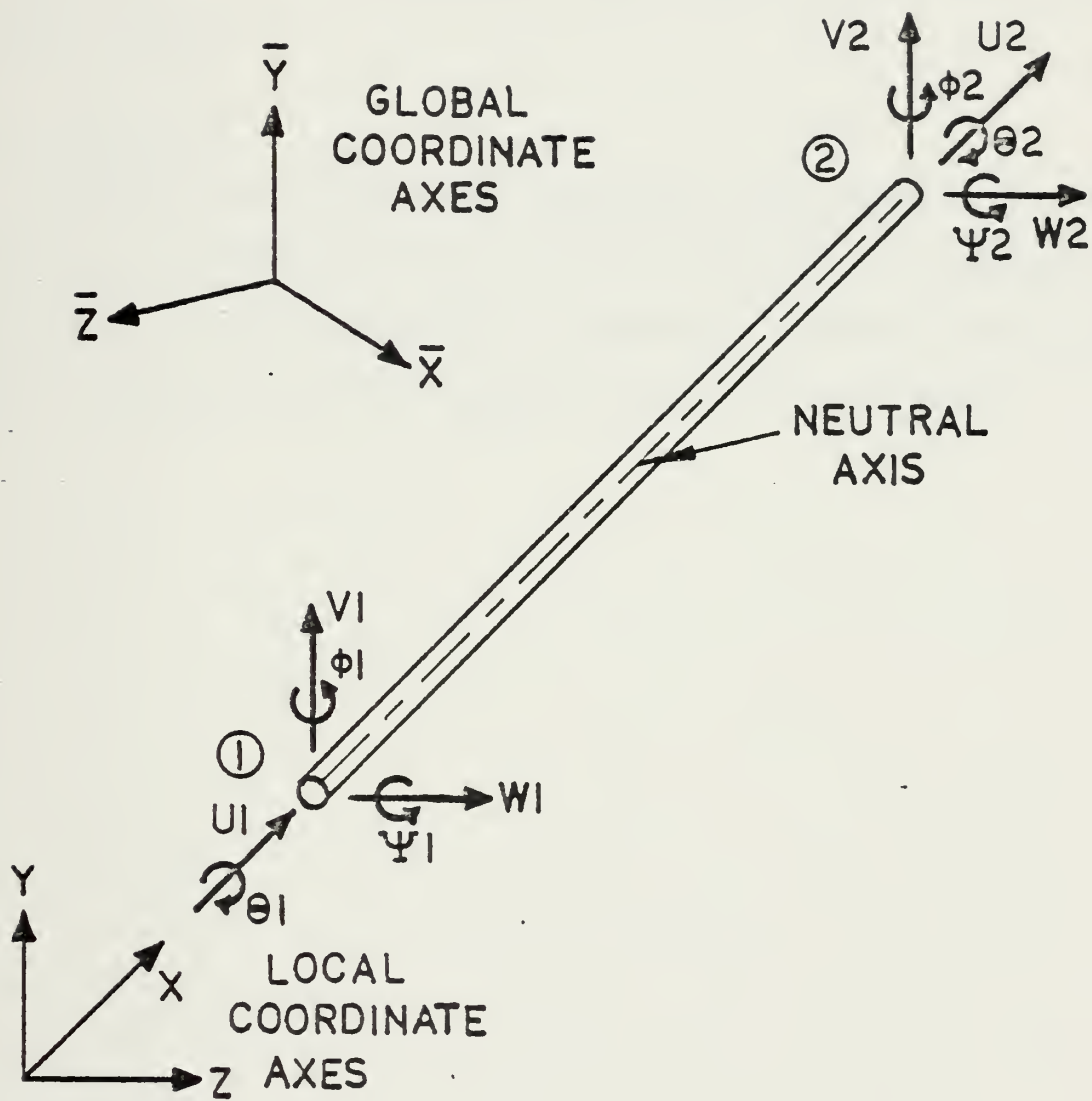


Figure 2.1 FORCE ORIENTATION CONVENTION FOR AN ELEMENT





method of Bathe and Wilson [Ref. 5] is used to solve for the desired number of lowest eigenvalues and the associated eigenvectors. This method is reasonably efficient for a small number of lowest frequencies for a large problem, and is well suited for re-analysis when small changes are made in the design.

#### D. GRADIENTS

Gradients are currently calculated with respect to member sizes and coordinates only by finite difference techniques. Inclusion of the capability to calculate gradients analytically is identified as a needed extension to this work.



### III. OPTIMIZATION

#### A. INTRODUCTION

The primary objective of structural optimization is to design systems that efficiently perform specified purposes. Selection of a specific optimizing algorithm must take into account the following: 1) the structure should be analyzed as few times as possible; 2) the algorithm should minimize the amount of gradient information required; 3) the algorithm should provide reasonable assurance that an optimum or near-optimum design will be reached.

#### B. GENERAL FORMULATION

The general statement of inequality constrained minimization is as follows:

Minimize

$$F(\tilde{X}) \quad (4.1)$$

Subject to:

$$G_j(\tilde{X}) \leq 0 \quad j=1,m \quad (4.2)$$

$$x_i^l \leq x_i \leq x_i^u \quad i=1,n \quad (4.3)$$

where  $F(\tilde{X})$  is the objective function to be minimized. The functions  $G_j(\tilde{X})$  are the set of inequality constraints to be met. The vector  $\tilde{X}$  contains the design variables.



The inequality constraints,  $G_j(\underline{X}) \leq 0 \quad j=1,m$ , must be satisfied for the design to be accepted as feasible. Side constraints,  $x_i^l$  and  $x_i^u$ , are lower and upper bounds on the design variables. The objective function must be minimized as much as possible while still satisfying all inequality constraints. In the case that it is not possible to satisfy all constraints, the most nearly feasible solution must be found. Felix and Vanderplaats [Ref. 4] is an excellent source for the basic structural design formulation.

### C. DESIGN VARIABLES

The vector  $\underline{X}$  contains the design variables; in this case, member characteristic dimensions for frame elements, cross-sectional areas for truss elements, and spacial coordinates of the joints. The user may elect to optimize the structure weight with respect to any combination of the above variables.

For truss elements, where normal stress is dependent only upon the magnitude of the cross-sectional area of an element and not the distribution of that area, it is sufficient to use the area as the design variable as long as the Euler buckling stress can be related to the cross-sectional area. For frame elements where stresses are dependent on area distribution, more flexibility is allowed by varying two characteristic dimensions and allowing the code to calculate the section properties from these.



In the case of tubular elements, the characteristic dimensions are mean diameter and wall thickness; from which area, bending and polar moments, and maximum radial dimensions are generated.

The optimum geometry problem requires that the joint coordinates be design variables. The x, y, and z coordinates of a joint are treated as separate design variables.

In many cases it is desirable to link a set of design variable together to preserve symmetry, limit the number of variables to be solved, or to limit the number of unique elements to be manufactured. The code has provisions for design variable linking by which two or more variables may be linked in equality or some fixed ratio.

#### D. OBJECTIVE FUNCTION

The objective function under consideration is weight

$$F(\tilde{X}) = \sum_{i=1}^{NE} \rho_i A_i L_i \quad (4.4)$$

where  $\rho_i$  is the weight density (in consistent units) of the material of the  $i$ th element,  $A_i$  is the cross-section area of the  $i$ th element, and  $L_i$  is the length of the  $i$ th element and NE is the number of elements in the structure.

#### E. CONSTRAINTS

This code is designed to accommodate constraints on maximum normal stress, Euler buckling, local or shell buckling,





maximum joint displacements, and minimum natural frequencies of the structure. All constraint values are normalized.

### 1. Stress:

For truss elements, maximum normal stress  $\sigma_M$  is calculated directly from the element tensile forces. For frame elements; tensile stress  $\sigma_A$ , maximum bending and shear stresses  $\sigma_B$  and  $\sigma_T$  are calculated. Maximum and minimum normal stresses are

$$\sigma_{\max} = \max \text{ magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A^2 + 4\sigma_T^2)}}{2} \quad (4.5)$$

$$\sigma_{\min} = \min \text{ magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A^2 + 4\sigma_T^2)}}{2} \quad (4.6)$$

The upper and lower bounds on stress may be different for each member, but are taken to be the same for every loading condition.

### 2. Local or Thin Shell Buckling

The stress at which local or thin shell buckling occurs is given by:

$$\sigma_{L_i} = \frac{0.4E_i}{D_{m_i} / t_i} \quad (4.7)$$

where the subscript  $i$  corresponds to the member number,  $E_i$  is Young's modulus,  $D_{m_i}$  is the element's mean diameter, and  $t_i$  is the element's wall thickness.



#### F. DESIGN VARIABLE BOUNDS

Side constraints are imposed on the design variables as:

$$CD_i^l \leq CD_i \leq CD_i^u \quad (4.3)$$

CD is the characteristic dimension and  $CD_i^l$  and  $CD_i^u$  are the minimum and maximum allowable characteristic dimensions of the  $i$ th element, and are taken to be the same for all load cases. If, as is the case in a tubular element, geometry dictates that some relationship between the design variables cannot be exceeded, i.e., thickness cannot exceed the mean diameter, the user must arrange the bounds to preclude such an occurrence.

#### G. OPTIMUM GEOMETRY

Joint coordinates are treated as design variables with a separate design variable for each coordinate direction of a node. Coordinate design variables may also be linked.



## IV. PROGRAM FEATURES

### A. INTRODUCTION

Computer codes each have their own features and formats with which the user must become familiar if he is to use the code easily and efficiently. The SADX code developed in the course of this research has been designed with various options which are explained in this chapter. Chapter V contains a User's Manual with sample data for a typical problem that might be solved with this code: a truss-braced cantilever beam. This problem along with other numerical examples will be presented in detail with results in Chapter VI.

The SADX code was written to be used as a stand alone analysis program or as an analysis code that could be easily be coupled to an optimizer (of the user's choice) through simple modifications to the main driver program.

### B. FEATURES

When the user supplies member areas, section types, characteristic dimensions, material data, connectivities and joint coordinates, along with a set of program control parameters; the analysis mode will calculate the weight of the structure. The addition of one or more sets of loading parameters will result in the calculation of resultant joint



displacements, member stresses, and/or forces for each load case along with the desired number of structure natural frequencies and modes. Design variables may be chosen as truss element areas, frame element characteristic dimensions, and joint coordinates. When coupled to an optimizer, the code will minimize the weight of the structure and print the final optimization information. The code is designed to be as simple to use as possible while retaining the flexibility for use on a variety of problems.

The code's modular construction allows the user to use frame element cross-sections other than tubular elements. This is done by reading in two characteristic dimensions for each frame element along with a section type identifier. Subroutine SADX85 is called to calculate the section properties, area, maximum radial dimensions, and bending and polar moments of inertia. The user may augment this subroutine to calculate section properties for whatever section type he may choose to work with.

Many computer codes require the definition of an auxiliary node to orient the principle axis of a non-axially symmetric element. In this code it is assumed that the element's local z-axis is parallel to the global x-z plane.

Pseudo-dynamic storage is used to allow storage of most data in one integer and one real array for more efficient use of storage.





Various print control options are available to tailor the printed output to match the user's desires.

Design variable linking is available to allow elements and joints to be grouped to maintain symmetry, limit the number of independent design variables, or reduce the variety of member sizes generated.

Optimization may be performed with respect to member size, with respect to structure geometry, or with respect to both.

Structures may be comprised of truss elements, frame elements, or a mix of the two types.

Structures may be optimized for multiple load cases with constraints imposed upon any combination of maximum normal stress, maximum joint displacements and rotations, Euler and local buckling, and a specified number of minimum natural frequencies in free vibration. Separate displacement constraints may be imposed for each load case. Both consistent and lumped mass options are coded. Either forces or stresses or both can be output. The user may decide whether to include the structure's weight and the fixed masses as loads applied to the structure.

#### C. EXAMPLE

The following example of the truss-braced cantilever beam presented in Tables (I-V) demonstrates some of the options available in the code.



TABLE I

## TRUSS-BRACED CANTILEVER BEAM: INPUT CONTROL PARAMETERS

INPUT PARAMETERS FOR STRUCTURAL ANALYSIS AND DESIGN  
ROUTINE, "SADX"

## TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1

## CONTROL PARAMETERS

TOTAL NUMBER OF ELEMENTS,	NE=	4
TOTAL NUMBER OF BAR ELEMENTS,	NEB=	2
TOTAL NUMBER OF FRAME ELEMENTS,	NEF=	2
TOTAL NUMBER OF JOINTS,	NJ=	5
JOINT MAXIMUM DEGREES OF FREEDOM,	JCM=	6
JOINT CONSTRAINT VARIABLE,	NCJ=	3
NUMBER OF MATERIAL TYPES,	NMT=	2
NUMBER OF LOAD CONDITIONS,	NLC=	2
NUMBER OF EIGENVALUES,	NEIG=	1
NO. OF EIGENVALUES CALCULATED,	NEIG1=	2
NUMBER OF FIXED MASSES,	NFMAS=	1
EULER BUCKLING CONSTRAINT ID,	NEUBC=	1
LOCAL BUCKLING CONSTRAINT ID,	LBUCK=	1
NO. OF DISPL. CONSTRAINTS,	NDSPLC=	2
NO. OF FREQ. CONSTRAINTS,	NFREQ=	1
LUMPED MASS OPTION,	LMAS=	0
FORCE/STRESS PRINT OPTION,	NSTRES=	2
OPTIMUM SIZE/BOTH/GEOM OPTION	IDVCLC=	2
STRUCTURE WEIGHT AS LOADS OPTION	NSTW=	1
FIXED MASSES AS LOADS OPTION	NFMW=	1

ACCELERATION DUE TO GRAVITY, GRAV = 0.38640E+03  
EIGENVALUE CONVERGENCE TOLERANCE, EPSEIG = 0.10000E-03



TABLE II

EXAMPLE 1: JOINT COORDINATE AND MEMBER INPUT DATA

JOINT	COORDINATES			
JOINT	X	Y	Z	
1	0.0	0.0	0.0	
2	0.1000E+03	0.0	0.0	
3	0.2000E+03	0.0	0.0	
4	0.0	0.1500E+03	0.0	
5	0.0	0.0	0.5000E+02	

COORDINATE DESIGN VARIABLES						
JOINT	DESIGN VARIABLE			MULTIPLIER		
	X	Y	Z	X	Y	Z
1	C	0	C	0.0	0.0	0.0
2	C	0	C	0.0	0.0	0.0
3	C	0	C	0.0	0.0	0.0
4	C	1	C	0.1000E+01	0.1000E+01	0.1000E+01
5	C	0	C	0.1000E+01	0.1000E+01	0.1000E+01

## ELEMENT INFORMATION FOR BAR ELEMENTS

## ELEMENT-JOINT RELATIONSHIPS

LAG	NODE1	NODE2	MATL	DVAR1	AREA	LENGTH
1	2	4	1	1	0.3000E+01	0.1803E+03
2	2	5	1	2	0.3000E+01	0.1118E+03

## ELEMENT INFORMATION FOR FRAME ELEMENTS

## ELEMENT-JOINT RELATIONSHIPS ELEMENT PROPERTIES

ELEMENT NUMBER 3							
NODE1	NODE2	MATL	1ST DESVAR	2ND DESVAR			
1	2	2	3	4			
AREA	LENGTH	Z-MOMENT	Y-MOMENT	ZMAX	YMAX		
0.157E+C2	0.100E+03	0.511E+02	0.511E+02	0.300E+01	0.300E+1		

ELEMENT NUMBER 4							
NODE1	NODE2	MATL	1ST DESVAR	2ND DESVAR			
2	3	2	3	5			
AREA	LENGTH	Z-MOMENT	Y-MOMENT	ZMAX	YMAX		
0.157E+C2	0.100E+03	0.511E+02	0.511E+02	0.300E+01	0.300E+1		



TABLE III

## EXAMPLE 1: SAMPLE DISPLACEMENT AND FORCE/STRESS OUTPUT

AC. CP ELEMEN7S = 2

LNG	LOAD CCND	TENSILE FORCE IN X	MAX STRESS
1	1	-0.7337E+04	-0.6628E+03
2	2	0.1344E+04	0.4449E+03

LNG	LOAD CCND	TENSILE FORCE IN X	MAX STRESS
1	1	0.7428E+04	0.8740E+03
2	2	-0.2413E+05	-0.4016E+04

NC. OF FRAME ELEMENTS = 2

ELEMENT	LOAD CCND	NCCE	TENSILE FORCE IN X DIREX	SHEAR FORCE IN Y DIREX	SHEAR FORCE IN Z DIREX	TORSION MOMENT ABOUT X AXIS	BENDING MOMENT ABOUT Y AXIS	BENDING MOMENT ABOUT Z AXIS	MAX STRESS
3	1	LCB HIGH	-0.1757E+04	-0.1066E+04	-0.3395E+01	0.0	-0.3395E+03	0.3515E+05	-0.7632E+04
3	2	LCB HIGH	-0.6647E+04	-0.4187E+03	-0.1482E+04	0.0	0.4816E+05	-0.1332E+05	0.1447E+05

ELEMENT	LOAD CCND	NCCE	TENSILE FORCE IN X DIREX	SHEAR FORCE IN Y DIREX	SHEAR FORCE IN Z DIREX	TORSION MOMENT ABOUT X AXIS	BENDING MOMENT ABOUT Y AXIS	BENDING MOMENT ABOUT Z AXIS	MAX STRESS
4	1	LCB HIGH	-0.4883E-03	-0.7145E+03	-0.4768E-05	0.0	0.1373E-03	-0.7145E+05	-0.2572E+05
4	2	LCB HIGH	-0.3906E-02	-0.2855E+03	-0.1000E+04	0.0	-0.1000E+06	0.2855E+05	0.3800E+05

EIGENVALUES AND EIGENVECTORS

MODE NUMBER = 1  
 FREQUENCY = 0.4888E+02 CPS  
 EIGENVALUE = 0.2631E+03 HPS  
 EIGENVECTOR = 0.6927E+05  
 EIGENVECTOR = 0.6927E+05  
 EIGENVECTOR = 0.6927E+05

JCINT	1	2	3
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	-0.2347E-01	-0.3794E-01	-0.7450E-01
4	-0.5077E-01	-0.1074E-01	0.1583E-03
5	-0.2342E-01	-0.1715E-01	0.10000E+01

LOAD CONDITION 1

JNT	X-DISPL	Y-DISPL	Z-DISPL	ROT ABT X	ROT ABT Y	ROT ABT Z	T ABT Z
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.105E-03	-0.275E-02	-0.137E-03	0.0	0.206E-05	-0.567E-04	0.5664E-04
3	-0.105E-03	-0.105E-01	-0.343E-03	0.0	0.206E-05	-0.875E-04	0.8748E-04
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

LOAD CONDITION 2

JNT	X-DISPL	Y-DISPL	Z-DISPL	ROT ABT X	ROT ABT Y	ROT ABT Z	T ABT Z
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.226E-03	-0.371E-02	-0.187E-02	0.0	0.416E-04	-0.847E-04	0.8468E-04
3	-0.226E-03	-0.161E-01	-0.784E-02	0.0	0.688E-04	-0.143E-03	0.1426E-03
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0





TABLE IV

EXAMPLE 1: SAMPLE CONSTRAINT OUTPUT INFORMATION

DISPLACEMENT CONSTRAINTS START AT NUMBER 2 AND STOP AT NUMBER 5

TRUSS ELEMENT STRESS CONSTRAINTS  
START AT NUMBER 6 AND STOP AT NUMBER 17

FRAME ELEMENT STRESS CONSTRAINTS  
START AT NUMBER 18 AND STOP AT NUMBER 41

THE NUMBER OF CONSTRAINTS NCTOT = 41

1)	-.408882E+C2	-.161055E+01	-.389445E+00	-.258895E+00
5)	-.174111E+C1	-.981588E+00	-.101841E+C1	-.943857E+00
9)	-.101236E+C1	-.98764CE+00	-.103769E+01	-.102428E+C1
13)	-.975722E+CC	-.102139E+01	-.888444E+00	-.111156E+01
17)	-.901716E+CC	-.126755E+C1	-.732450E+CC	-.152875E+C1
21)	-.471251E+CO	-.118559E+01	-.972695E+00	-.597988E+00
25)	-.14C201E+C1	-.225C14E+CO	-.177499E+C1	-.127432E+01
29)	-.959641E+CO	-.171444E+01	-.285557E+CO	-.100000E+01
33)	-.999999E+CO	-.123411E+01	-.965558E+00	-.581741E-04
37)	-.199994E+C1	-.999998E+00	-.10C000E+C1	-.132766E+01
41)	-.951795E+CO			



# TABLE V

## EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

### FINAL OPTIMIZATION INFORMATION

OBJ = C.5875C7E+C3

#### DECISION VARIABLES (X-VECTOR)

1) C.348C8E+01 0.84992E+01 0.48389E+01 0.21898E+00 0.15576E+00  
7) C.45432E+02

#### CONSTRAINT VALUES (G-VECTOR)

1) -C.40888E+02 -0.161C6E+01 -0.38945E+00 -0.25889E+00 -0.17411E+01  
7) -C.10184E+01 -0.94338E+00 -0.10124E+01 -0.98764E+00 -0.10377E+01  
13) -C.97572E+00 -0.10214E+01 -0.88844E+00 -0.11116E+01 -0.90172E+00  
19) -C.73245E+00 -0.15237E+01 -0.47125E+00 -0.11856E+01 -0.97270E+00  
25) -C.1402C8E+01 -0.22501E+00 -0.17750E+01 -0.12743E+01 -0.95964E+00  
31) -C.28556E+00 -0.10000E+01 -C.10000E+01 -0.12341E+01 -0.96556E+00  
37) -C.19999E+01 -0.10000E+01 -0.10000E+01 -0.13277E+01 -0.95180E+00

THERE ARE 1 ACTIVE CONSTRAINTS  
CONSTRAINT NUMBERS ARE  
36

THERE ARE 0 VIOLATED CONSTRAINTS

THERE ARE 0 ACTIVE SIDE CONSTRAINTS

#### TERMINATION CRITERION

ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS = 12

OBJECTIVE FUNCTION WAS EVALUATED 114 TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED 114 TIMES

THIS RUN REQUIRED 116 STRUCTURAL ANALYSES

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 2.79

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS

WEIGHT= C.58751E+C3

TOTAL WEIGHT INCLUDING FIXED MASSES

TOTAL WEIGHT= C.83751E+03

#### JOINT COORDINATES

JOINT	X	Y	Z
1	0.0	0.0	0.0
2	0.1C0C0E+C3	0.0	0.0
3	0.2C0C0E+C3	0.0	0.0
4	0.0	0.84259E+02	0.0
5	0.0	0.0	0.45432E+02

#### ELEMENT INFORMATION FOR BAR ELEMENTS

##### ELEMENT-JOINT RELATIONSHIPS

ELEMENT	NODE 1	NODE 2	AREA	LENGTH
1	2	4	C.3481E+C1	0.1308E+03
2	2	5	0.8499E+01	0.1098E+03

#### ELEMENT INFORMATION FOR FRAME ELEMENTS

##### ELEMENT-JOINT RELATIONSHIPS

LAN	NODE1	NODE2	AREA	LENGTH	CHAR.DIM.1	CHAR.DIM.2
3	1	2	0.3329E+01	0.1000E+03	0.4839E+01	0.2190E+00
4	2	3	0.2368E+01	0.1000E+03	0.4839E+01	0.1558E+00



## V. USER GUIDE

### A. INTRODUCTION

In developing any computer code for engineering analysis, it is necessary to additionally develop concise, easily understood documentation. This SADX USER'S GUIDE is written to be easily understood by the user having only minimal knowledge of the FORTRAN language. The format follows that of the optimization code, COPES/CONMIN [Ref. 2].

This chapter is devoted to acquainting the user with the code and necessary input data.

### B. DESIGN EXAMPLE

The simple example of a four-element combined truss/frame structure is used to demonstrate some of the features of the SADX program.

The structure is shown in Figure 5.1, and consists of two tubular frame elements along the x-axis with two truss braces to the y and z axes from the joint between the frame elements. A non-structural fixed mass is attached at the outboard end of the second frame element where two loads are applied.

### C. SADX DATA

The SADX program reads data from unit 5 and writes output on unit 6. Units 30 and 40 are used as scratch files.



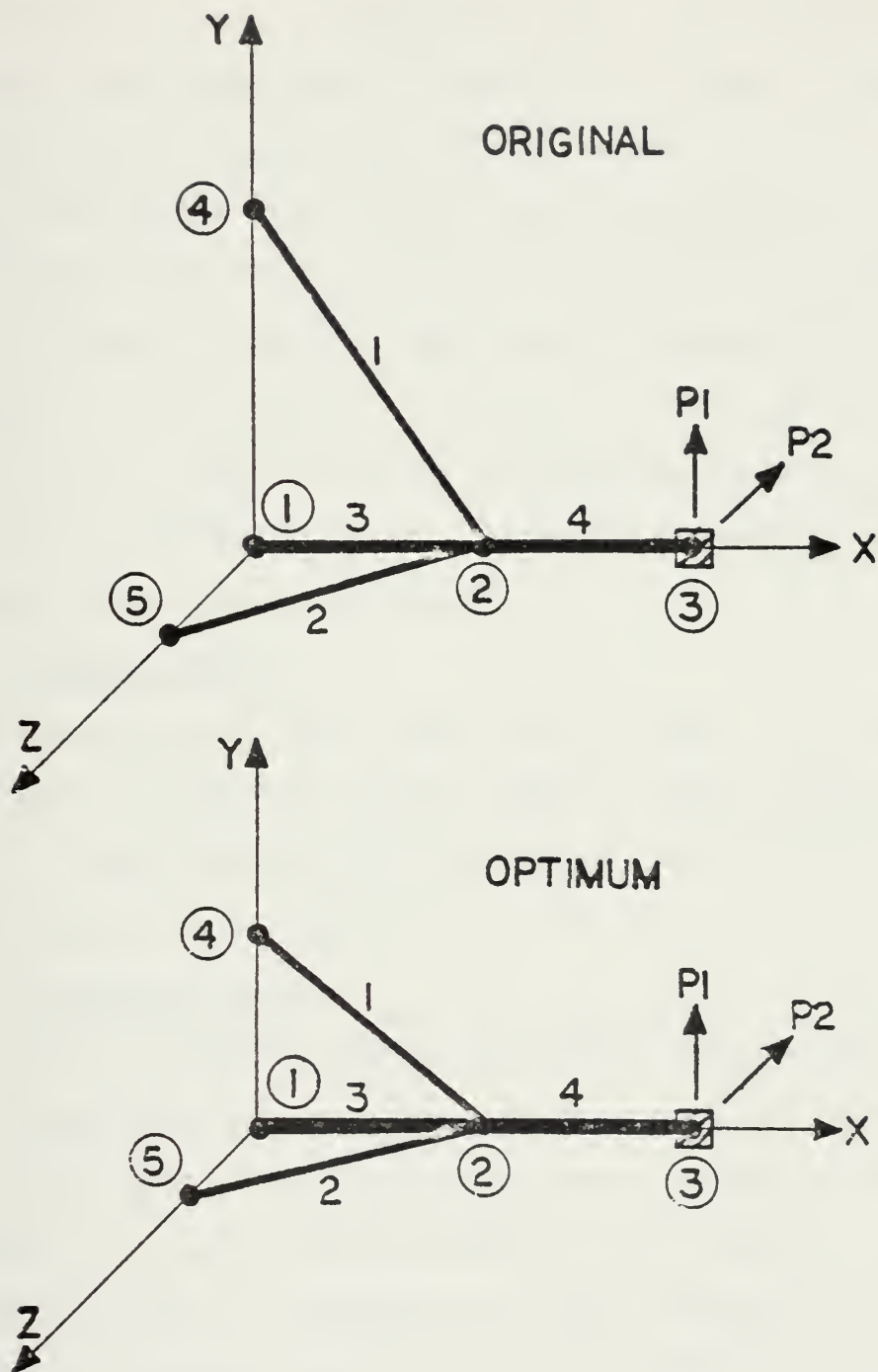


Figure 5.1 TRUSS-BRACED CANTILEVER BEAM





The scratch file numbers may be changed by changing two cards at the beginning of subroutine SADX01. The SADX program has the capability to read unformatted data. The following sections define the data which is required by SADX. The data is segmented into "BLOCKS" for convenience.

SADX data begins with a TITLE card and ends with a END card. Comment cards may be inserted anywhere in the SADX data stack prior to the END card, and are identified by a dollar sign (\$) in column 1. Data may be of either the "I10" or "F10.0" type or may be free-format separated by commas with no imbedded blanks. Lines of formatted and unformatted data may be intermixed.

#### 1. Formatted Data

Formats are of "I10" and "F10.0" type. "I" formats must be right justified, and "F" formats must have the decimal point. The number of cards read per data block is listed at the bottom of each block.

#### 2. Unformatted Data

While the USER'S MANUAL data sheet defines SADX data in formatted fields of ten, the data may actually be read in a simplified fashion by separating data by commas or one or more blanks. If more than one number is contained on an unformatted data card, a comma must appear somewhere on the card. If exponential numbers such as  $2.5 \times 10$  are read on an unformatted card, there must be no imbedded blanks. Unformatted cards may be intermingled with formatted cards. Real numbers on an unformatted card must have a decimal point.



## EXAMPLES

Unformatted data

5,7,3.2,1.3+6,-5,2

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	5	7	3.2	1.3+6	-5	0	2	

Unformatted data

2

2,3

2 3

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	2							
	2	3						

2 3

NOTE: The third line of data contains no commas and is therefore assumed to be already formatted.

Placement of more than eight unformatted data on a card will create two (or more) formatted cards as required. Fields of zeros will be created if more data are required than are filled on an unformatted card.

### D. CONSTRAINTS

Constraints are calculated and stored in the G vector as listed in the following chart. The total number of constraints

$$\text{NCON} = \text{NFREQ} + 2 * \text{NDSPLC} + \text{NLC} * (2 * \text{NEB} + 4 * \text{NEF} + \text{NEB} + 2 * \text{NEF})$$

freq	displ	stress	stress	buckl	buckl
------	-------	--------	--------	-------	-------



Where NCON is the total number of constraints, NFREQ is the number of frequency constraints, NDSPLC is the number of displacement constraints, NLC is the number of load cases imposed, NEB is the number of bar or truss elements, and NEF is the number of frame elements. When any of the constraints are missing from the G vector, all constraints are moved up in the vector. For example, if there is no frequency constraint, then a displacement constraint would fill the first location of the G vector.

CONSTRAINTS ARE STORED IN THE G VECTOR IN  
THE FOLLOWING ORDER:

NFREQ FREQUENCY CONSTRAINTS

2\*NDSPLC JOINT DISPLACEMENT CONSTRAINTS

STRESS CONSTRAINTS ARE STORED ELEMENT BY ELEMENT

FOR A GIVEN ELEMENT CONSTRAINTS ARE STORED BY LOAD CASE

FOR A GIVEN TRUSS ELEMENT AND LOAD CASE,

CONSTRAINTS ARE STORED:

TENSILE STRESS LOWER LIMIT

TENSILE STRESS UPPER LIMIT

EULER BUCKLING STRESS LIMIT (IF APPLICABLE)

FOR A GIVEN FRAME ELEMENT AND LOAD CASE,

CONSTRAINTS ARE STORED:

NORMAL STRESS AT LOW NODE LOWER LIMIT

NORMAL STRESS AT LOW NODE UPPER LIMIT

NORMAL STRESS AT HIGH NODE LOWER LIMIT



NORMAL STRESS AT HIGH NODE UPPER LIMIT  
EULER BUCKLING STRESS LIMIT (IF APPLICABLE)  
LOCAL BUCKLING STRESS LIMIT (IF APPLICABLE)

#### E. EXAMPLE

The initial configuration of the braced cantilever beam is shown in Figure 5.1 Stress constraints are imposed as well as constraints on Euler and local buckling, displacement, and first fundamental frequency. A non-structural fixed mass is applied at the tip of the beam, and two load conditions ( $P_1$ , and  $P_2$ ) are imposed. The structure's own weight will be considered as an imposed load as will be the fixed mass.

The linking of design variables is demonstrated by linking the mean diameters of the two frame members ( $D_1$ , and  $D_2$  with  $D_1=D_2$ ). Member size variables are: truss member areas ( $A_1$ , and  $A_2$ ), frame member mean diameters ( $D_1$ , and  $D_2$ ), and frame member thicknesses ( $T_1$ , and  $T_2$ ). Member sizing DESIGN VARIABLES are:  $XA(1)=A_1$ ,  $XA(2)=A_2$ ,  $XA(3)=D_1=D_2$ ,  $XA(4)=T_1$ ,  $XA(5)=T_2$ .

Geometry variables are the attachment points (joints 4 and 5) of the two truss members on the y and z axes ( $Y_4, Z_5$ ). Coordinate DESIGN VARIABLES are:  $XC(1)=Y_4$  and  $XC(2)=Z_5$ . The structure's weight is then optimized with respect to member sizes and structure geometry for a total of seven design variables.





## 1. Properties/Conditions

Two material types are used: type 1, aluminum, is used for the truss members; and type 2, steel, is used for the frame members. The weight densities of the materials ( $\rho$ ) are:

$$\text{type 1} = 0.1 \text{ lb/in}^3$$

$$\text{type 2} = 0.3 \text{ lb/in}^3$$

The Young's moduli of the materials (E) are:

$$\text{type 1 } E = 10.0\text{E}+6 \text{ psi}$$

$$\text{type 2 } E = 29.0\text{E}+6 \text{ psi}$$

The non-structural fixed mass attached at the tip of the structure weights 250 lb. The applied loads are:

$$P1 \quad 1000.0 \text{ lb in the } +y \text{ direction}$$

$$P2 \quad 1000.0 \text{ lb in the } -z \text{ direction}$$

The acceptable maximum normal stresses are:

$$\text{type 1 } -25000 \text{ psi} \leq \sigma_{\max} \leq 25000 \text{ psi}$$

$$\text{type 2 } -36000 \text{ psi} \leq \sigma_{\max} \leq 36000 \text{ psi}$$

Displacement limits, imposed upon joint number 3 (the tip) for each load case in the direction of loading, are:

$$\text{load case 1} \quad y\text{-direction} \quad +/\text{- } 3.0 \text{ in.}$$

$$\text{load case 2} \quad z\text{-direction} \quad +/\text{- } 3.5 \text{ in.}$$

Bounds, placed on the positions of joints 4 and 5 along the y and z axes, are:

$$\text{joint 4} \quad y\text{-coordinate} \quad 0.0 \text{ inches to } 200.0 \text{ inches}$$

$$\text{joint 5} \quad z\text{-coordinate} \quad 0.0 \text{ inches to } 100.0 \text{ inches}$$

The minimum natural frequency of the structure is constrained to be greater than 1Hz.



## 2. Input Control Parameters

The following input control parameters are given for ease of following the example:

NEB=2	NEF=2	NJ=5	NCJ=3
NMT=2	IDVCLC=2	NDJ=2	NEUBC=1
LBUCK=1	NFREQ=1	NFMASS=1	NEIG=1
NEIG1=2	NPRI=0	NLC=2	NDSPLC=2
NSTRES=2	NSTW=1	NFMW=1	

Table VI is a listing of commonly used nomenclature.

The following USER'S MANUAL is divided into blocks A through P. Appearing directly below each data field line are the parameters for the TRUSS-BRACED CANTILEVER BEAM example. It is important to note that the user may choose any consistent system of units.



TABLE VI  
COMMON VARIABLE NOMENCLATURE

A	- MEMBER'S CROSS-SECTIONAL AREA
BL	- LOWER BOUND ON DISPLACEMENTS
BU	- UPPER BOUND ON DISPLACEMENTS
CHARDIM 1, 2	- CHARACTERISTIC DIMENSIONS FOR FRAME MEMBERS FOR LSECT.EQ.1: MEAN DIAMETER AND THICKNESS
DIR	- DIRECTION 1=X, 2=Y, 3=Z, 4=rot about x, 5=rot about y, 6=rot about z.
E	- YOUNGS MODULUS
EPSEIG	- CONVERGENCE TOLERANCE OF EIGENVALUE SOLUTIONS (DEFAULT=.0001)
FC 1, ..., FC N	- LOWER BOUND ON FIRST, SECOND, ETC. SYSTEM NATURAL FREQUENCY
FX	- LOAD FORCES APPLIED IN THE X DIRECTION
FY	- LOAD FORCES APPLIED IN THE Y DIRECTION
FZ	- LOAD FORCES APPLIED IN THE Z DIRECTION
GRAV	- ACCELERATION DUE TO GRAVITY (DEFAULT= 386.4)
IDVCLC	- THE OPTIMIZATION OPERATION IDENTIFIER 1 FOR OPTIMUM MEMBER SIZE ONLY 2 FOR BOTH OPTIMUM MEMBER SIZE AND GEOMETRY 3 FOR OPTIMUM GEOMETRY ONLY
IX	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE X-DOF IS CONSTRAINED
IY	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE Y-DOF IS CONSTRAINED
IZ	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE Z-DOF IS CONSTRAINED
IXX	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE X-AXIS IS CONSTRAINED
IYY	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Y-AXIS IS CONSTRAINED
IZZ	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Z-AXIS IS CONSTRAINED
JN	- JOINT NUMBER (GLOBAL) KEULER- EULER BUCKLING COEFFICIENT FOR BAR ELEMENTS
LBUCK	- LOCAL BUCKLING CONSTRAINT IDENTIFIER IF LBUCK.NE.0, LOCAL BUCKLING CONSTRAINTS WILL BE APPLIED TO TUBULAR FRAME MEMBERS
LC	- LOAD CONDITION
LMASS	- LUMPED MASS OPTIONS IF LMASS.EQ.0 CONSISTENT MASS MATRIX USED IF LMASS.NE.0 LUMPED MASS MATRIX USED
LNO	- ELEMENT NUMBER
LSECT	- CROSS-SECTION TYPE IDENTIFIER LSECT.EQ.1 INDICATES A TUBULAR MEMBER
NCJ	- THE NUMBER OF CONSTRAINED JOINTS
NDJ	- THE NUMBER OF JOINTS WITH (OR LINKED TO) DESIGN VARIABLES
ND SG 1	- TRUSS MEMBER AREA DESIGN VARIABLE NUMBER
ND SG 2	- COORDINATE DESIGN VARIABLE NUMBER
ND SG 3	- FRAME MEMBER CHARACTERISTIC DIMENSION 1 DESIGN VARIABLE NUMBER
ND SG 4	- FRAME MEMBER CHARACTERISTIC DIMENSION 2 DESIGN VARIABLE NUMBER



NDSPLC	- THE NUMBER OF DISPLACEMENT CONSTRAINT SETS
NEB	- THE NUMBER OF TRUSS ELEMENTS
NEF	- THE NUMBER OF FRAME ELEMENTS
NEIG	- NUMBER OF PRECISE EIGENVALUES TO BE FOUND
NEIG1	- NUMBER OF EIGENVALUE/EIGENVECTOR TO BE EVALUATED DEFAULT =MIN(2*NEIG, NEIG+8)
NEUBC	- EULER BUCKLING CONSTRAINT IDENTIFIERS. IF NEUBC.NE.0 EULER BUCKLING CONSTRAINTS WILL BE IMPOSED ON BAR AND FRAME ELEMENTS
NFMASS	- NUMBER OF NON-STRUCTURAL FIXED MASSES ATTACHED TO THE STRUCTURE
NFMW	- FIXED MASS WEIGHT IDENTIFIER IF(NFMW.NE.0) FIXED MASSES WILL BE CONSIDERED AS LOADS
NFREQ	- NUMBER OF FREQUENCY CONSTRAINTS
NID	- NUMBER OF INDEPENDENT DEGREES OF FREEDOM
NJ	- THE NUMBER OF JOINTS
NLC	- NUMBER OF LOADING CONDITIONS
NLJ	- NUMBER OF LOADED JOINTS FOR THIS LOAD CONDITION
NMT	- NUMBER OF SEPARATE MATERIAL TYPES
NPRI	- INPUT PRINT CONTROL IF NPRI.NE.0 INPUT VALUES are NOT PRINTED IF NPRI.EQ.5 LOCI/LOCRI/IA/RA ARRAYS PRINTED
NSTRES	- THE FORCE/STRESS PRINT IDENTIFIER IF NSTRES.EQ.0 MEMBER FORCES PRINTED IF NSTRES.EQ.1 MEMBER STRESSES PRINTED IF NSTRES.EQ.2 BOTH are PRINTED
NSTW	- STRUCTURE WEIGHT IDENTIFIER IF(NSTW.NE.0) THE STRUCTURE'S OWN WEIGHT WILL BE CONSIDERED AS LOADS
POISSN	- POISSON'S RATIO
RHO	- MATERIAL WEIGHT DENSITY
SIGMIN	- MINIMUM ALLOWABLE NORMAL STRESS
SIGMAX	- MAXIMUM ALLOWABLE NORMAL STRESS
TX	- TORSIONAL MOMENT APPLIED ABOUT THE X-AXIS
TY	- TORSIONAL MOMENT APPLIED ABOUT THE Y-AXIS
TZ	- TORSIONAL MOMENT APPLIED ABOUT THE Z-AXIS
XA	- INITIAL VALUE OF AREA DESIGN VARIABLE
XAL	- LOWER BOUNDS ON XA
XAU	- UPPER BOUNDS ON XA
XC	- INITIAL VALUE OF COORDINATE DESIGN VARIABLE
XCL	- LOWER BOUNDS ON XC
XCU	- UPPER BOUNDS ON XC





DATA BLOCK A

DESCRIPTION: Title Card

Format and Example

TITLE	FORMAT
	20A4

TRUSS-BRACED CANTILEVER BEAM
------------------------------

FIELD

CONTENTS

- 1 ANY 80 CHARACTER TITLE MAY BE GIVEN ON THIS  
LINE



DATA BLOCK B

DESCRIPTION: Control Parameters

Format and Example

NEB	NEF	NJ	NCJ	NMT	IDVCLC	NDJ	FORMAT 7I10
-----	-----	----	-----	-----	--------	-----	----------------

2	2	5	3	2	2	2
---	---	---	---	---	---	---

NEUBC	LBUCK	NFREQ	NFMASS	NEIG	NEIG1	NPRI	format 7I10
-------	-------	-------	--------	------	-------	------	----------------

1	1	1	1	1	2	0
---	---	---	---	---	---	---

NLC	NDSPIC	NSTRES	NSIW	NFMW		FORMAT 5I10
-----	--------	--------	------	------	--	----------------

2	2	2	1	1
---	---	---	---	---

NOTE: DEFINITIONS OF PROGRAM INPUT CONTROL  
PARAMETERS ARE LISTED ON NEXT PAGE



FIELDCONTENT

## FIRST CARD

- 1 NEB-number of bar elements
- 2 NEF-number of frame elements
- 3 NJ-number of joints
- 4 NCJ-number of constrained joints
- 5 NMT-number of seperate material types
- 6 IDVCLC-design variable control parameter  
If (IDVCLC.EQ.1) NDV=NDVAR1  
optimizes wrt member size only  
If (IDVCLC.EQ.2) NDV=NDVAR1+ NDVAR2  
optimizes wrt member size and geometry  
If (IDVCLC.EQ.3) NDV=NDVAR2  
optimizes wrt geometry only
- 7 NDJ-total linked and design variable joints  
(i.e. number of 'movable' joints)

## SECOND CARD

- 1 NEUBC-Euler buckling constraint identifier  
If (NEUBC.NE.0) EULER buckling constraints  
will be imposed on bar elements
- 2 LBUCK-local buckling constraint identifier  
If (LBUCK.NE.0) local buckling constraints  
will be imposed on tubular frame elements
- 3 NFREQ-number of frequency constraints
- 4 NFMASs-number of fixed masses attached to  
structure
- 5 NEIG-number of precise eigenvalues to  
be evaluated



- 6 NEIG1-number of eigenvalues to be evaluated  
DEFAULT=min. of (2\*NEIG , NEIG+8)
- 7 NPR1-print control identifier  
NPR1.ne.0 input info not printed  
NPR1.eq.5 RA/IA/LOCR/LDCI arrays  
will be printed for debugging

THIRD CARD

- 1 NLC-number of load conditions
- 2 NDSPLC-number of displacement constraints
- 3 NSTRES-force/stress print identifier  
If (NSTRES.EQ.0) stresses are printed  
If (NSTRES.EQ.1) forces are printed  
If (NSTRES.EQ.2) both are printed
- 4 NSTW-structure weight identifier  
If (NSTW.NE.0) the structure's weight is  
considered as loads
- 5 NFMW-fixed mass weight identifier  
If (NFMW.NE.0) the fixed masses are  
considered as loads





DATA BLOCK C

DESCRIPTION: Dynamic Analysis Information

Format and Example

LMASS	GRAV	EPSEIG		FORMAT
				I10,2F10.0

0	386.4	0.0
---	-------	-----

FIELD

CONTENTS

- 1 LMASS-lumped mass option (if LMASS.NE.0)  
the lumped mass matrix is used.
- 2 GRAV-accleration due to gravity  
(default=386.4 inches/sec<sup>2</sup>)
- 3 EPSEIG-convergence tolerance on eigenvalue  
solution. (default=.0001)



DATA BLOCK D

DESCRIPTION: Joint Coordinates

Format and Example

JN	X	Y	Z		FORMAT
					I 10,3F10.0

1	0.0	0.0	0.0
---	-----	-----	-----

2	100.0	0.0	0.0
---	-------	-----	-----

3	200.0	0.0	0.0
---	-------	-----	-----

4	0.0	150.0	0.0
---	-----	-------	-----

5	0.0	0.0	50.0
---	-----	-----	------

FIELD

CONTENTS

- 1 JN-joint coordinate number
- 2 X-x coordinate
- 3 Y-y coordinate
- 4 Z-z coordinate

NOTE: Number of cards read=NJ



DATA BLOCK E

Omit this block if NDJ=0 in BLOCK B

DESCRIPTION: Coordinate Design Variable Linking Data

Format and Example

JN	IX	IY	IZ	PCX	PCY	PCZ	FORMAT
							4i10,3f10.0

4	0	1	0	1.0	1.0	1.0
---	---	---	---	-----	-----	-----

5	0	0	2	1.0	1.0	1.0
---	---	---	---	-----	-----	-----

FIELD

CONTENTS

- 1 IX-design variable associated with x coord.
- 2 IY-design variable associated with y coord.
- 3 IZ-design variable associated with z coord.
- 4 PCX-participation coefficient of x-coord.
- 5 PCY-participation coefficient of y-coord.
- 6 PCZ-participation coefficient of z-coord.

NOTE: Number of cards read=NDJ



DATA BLOCK F

DESCRIPTION: Material Properties

Format and Example

E	RHO	SIGMIN	SIGMAX	KEULER	POISSN	FORMAT
						6F10.0

1.0E+7	0.1	-25000.	25000.	2.0	0.27
--------	-----	---------	--------	-----	------

2.9E+7	0.3	-36000.	36000.	2.0	0.27
--------	-----	---------	--------	-----	------

FIELD

CONTENTS

- 1 E-Young's Modulus
- 2 RHO-material density
- 3 SIGMIN-minimum allowable stress
- 4 SIGMAX-maximum allowable stress
- 5 KEULER-Euler buckling coefficient
- 6 POISSN-Poisson's ratio

NOTE: Number of cards read=NMT





## DATA BLOCK G

Omit this block if NEB=0 in BLOCK B

DESCRIPTION: Bar Element Information

Format and Example

LNC	NODE1	NODE2	MATCOD	NDSG1	A	LSECT	FORMAT
							5I10 f10,I10
3	2	4	1	1	3.0	1	
2	2	5	1	2	3.0	1	

### FIELD

### CONTENTS

- 1 LNO-element number
- 2 NODE1-global number associated with the element's 1st node
- 3 NODE2-global number associated with the element's 2nd node
- 4 MATCOD-material type of this element
- 5 NDSG1-design variable number associated with this element's area
- 6 A-member cross-sectional area
- 7 LSECT-cross-section type identifier  
LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEB



DATA BLOCK H

Omit this block if NEF=0 in BLOCK B

DESCRIPTION: Frame Element Information Format and Example

LNO	NODE1	NODE2	MATCOD	NDSG3	NDSG4	LSECT	FORMAT
							7I10

3	1	2	2	2	4	1
---	---	---	---	---	---	---

CHARDIM1	CHARDIM2		FORMAT
			2F10

5.0	1.0
-----	-----

4	2	3	2	3	5	1
---	---	---	---	---	---	---

5.0	1.0
-----	-----

FIELD

CONTENTS

- 1 LNO-element number
- 2 NODE1-global number associated with the element's 1st node
- 3 NODE2-global number associated with the element's 2nd node
- 4 MATCOD-material type of this element
- 5 NDSG3-design variable number associated with the element's 1st characteristic dimension
- 6 NDSG4-design variable number associated with the element's 2nd characteristic dimension
- 7 LSECT-cross-section type identifier  
LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEF



## DATA BLOCK I

DESCRIPTION: Joint Constraint Information

Format and Example

JN	IX	IY	IZ	IXX	IYY	IZZ	FORMAT
							7I10
1	1	1	1	1	1	1	
2	0	0	0	0	0	0	
3	0	0	0	0	0	0	
4	1	1	1	1	1	1	
5	1	1	1	1	1	1	

### FIELD

### CONTENTS

- 1 JN- joint number
- 2 IX- x-displacement constraint identifier.
- 3 IY- y-displacement constraint identifier.
- 4 IZ- z-displacement constraint identifier.
- 5 IXX- x-axis rotation constraint identifier.
- 6 IYY- y-axis rotation constraint identifier.
- 7 IZZ- z-axis rotation constraint identifier.  
if .NE.0 - corresponding DOF constrained

NOTE: Number of cards read=NCJ



# DATA BLOCK J

Omit this block if NLC=0 in BLOCK B.

DESCRIPTION: Joint Loading Information

Format and Example

NLJ		FORMAT I10
-----	--	---------------

1
---

JN	FX	FY	FZ	TX	TY	TZ	FORMAT I10,6F10
----	----	----	----	----	----	----	--------------------

2	0.0	1000.	0.0	0.0	0.0	0.0
---	-----	-------	-----	-----	-----	-----

1
---

2	0.0	0.0	-1000.	0.0	0.0	0.0
---	-----	-----	--------	-----	-----	-----

## FIELD

## CONTENT

- 1 NLJ-number of loaded joints for this load condition
- 1 JN-joint number
- 2 FX
- 3 FY- Forces in the X,Y,Z directions
- 4 FZ
- 5 TX
- 6 TY- Moments about the X,Y,Z axes
- 7 TZ

NOTE: Number of cards read per set=NLJ  
Number of sets of cards read=NLC





DATA BLOCK K

Omit this block if NFMASS=0 in BLOCK B

DESCRIPTION: Fixed Mass Information

Format and Example

JN	MASS	FORMAT
		I10, F10
3	250.0	

FIELD

CONTENTS

- 1 JN-joint number
- 2 MASS-point mass at joint (JN) in force units

NOTE: Number of cards read=NFMASS



DATA BLOCK L

Omit this block if IDVCLC=3

DESCRIPTION: Design Variable Information  
(MEMBER SIZE VARIABLES)

Format and Example

XA (1)	XA (2)	. . . . XA (NDVAR1)	FORMAT 8F10.0
--------	--------	---------------------	------------------

20.0	20.0	20.0	2.0	2.0
------	------	------	-----	-----

XAL (1)	XAL (2)	. . . .XAL (NDVAR1)	FORMAT 8F10.0
---------	---------	---------------------	------------------

0.50	0.50	4.0	0.10	0.10
------	------	-----	------	------

XAU (1)	XAU (2)	. . . .XAU (NDVAR1)	FORMAT 8F10.0
---------	---------	---------------------	------------------

25.0	35.0	25.0	2.5	4.0
------	------	------	-----	-----

FIELD

CONTENTS

- 1 XA-initial value of area design variables
- 2 XAL-lower bounds on area design variables
- 3 XAU-upper bounds on area design variables

NOTE: read one value of XA, XAL, XAU for each independent member size variable defined in BLOCKS G and H

Number of cards read = as required



DATA BLOCK M

Omit this block if IDVCLC=1

DESCRIPTION: Design Variable Information  
(COORDINATE VARIABLES)

Format and Example

XC (1)	XC (2)	. . . . XC (NDVAR2)	FORMAT
			8F10.0

150.0	50.0
-------	------

XCL (1)	XCL (2)	. . . . XCL (NDVAR2)	FORMAT
			8F10.0

0.0	0.0
-----	-----

XCU (1)	XCU (2)	. . . . XCU (NDVAR2)	FORMAT
			8F10.0

200.0	100.0
-------	-------

FIELD

CONTENTS

- 1 XC-initial value of coord. design variables
- 2 XCL-lower bounds on coord. design variables
- 3 XCU-upper bounds on coord. design variables

NOTE: read one value of XC,XCL,XCU for each  
independent coord. variable defined in BLOCK D

Number of cards read =as required.



## DATA BLOCK N

Omit this block if NDSPLC=0 in BLOCK B

DESCRIPTION: Joint Displacement Constraint Information

Format and Example

JN	DIR	LC	BL	BU	FORMAT
					3I10,2F10.0

3	2	1	-3.0	3.0
---	---	---	------	-----

3	3	2	-3.5	3.5
---	---	---	------	-----

### FIELD

### CONTENTS

- 1 JN-joint number
- 2 DIR-direction  
1=x,2=y,3=z displacement  
4=x,5=y,6=z rotation
- 3 LC-load condition
- 4 BL-lower bound on displacement
- 5 BU-upper bound on displacement

NOTE: Number of cards read= NDSPLC





DATA BLOCK 0

Omit this block if NFREQ=0 in BLOCK 3

DESCRIPTION: Frequency Constraint Information

Format and Example

FC1	FC2	FC3	.....FCN	FORMAT
				8F10.0

1.0
-----

FIELD

CONTENTS

- |   |  |
|---|--|
| 1 | FC1- lower bound on first natural frequency<br>constraint in Hz. (cycles per second)       |
| N | FCN- lower bound on NFREQ-th natural<br>frequency constraint in Hz.<br>(cycles per second) |

NOTE: Number of cards read = as required



DATA BLOCK P

DESCRIPTION: End card

Format and Example

END		FORMAT
		3A 1

END
-----

NOTE: This card MUST appear at the end of the  
SADX data.



## VI. NUMERICAL EXAMPLES

### A. INTRODUCTION

Design of three-dimensional truss and frame structures are presented herein and the corresponding numerical results are summarized to demonstrate the use of the SADX code.

The examples begin with the truss-braced cantiliver beam.

### B. EXAMPLE 1: TRUSS-BRACED CANTILIVER BEAM

The simple truss-braced cantiliver beam, as shown in Figure 6.1, has been previously used for the SADX USER's MANUAL example. It consists of two steel tubular frame members with a common outer diameter and different wall thicknesses arranged as a cantilever beam along the X-axis. There is a fixed 250 pound mass at the tip of the beam. Two aluminum truss members are attached from the beam midpoint to points on the Y and Z axes. This structure is designed for optimum member size and geometry under a set of two load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed mass and the structure's own weight are imposed as loads. There are five member size and two coordinate design variables, and a total of 41 constraints.



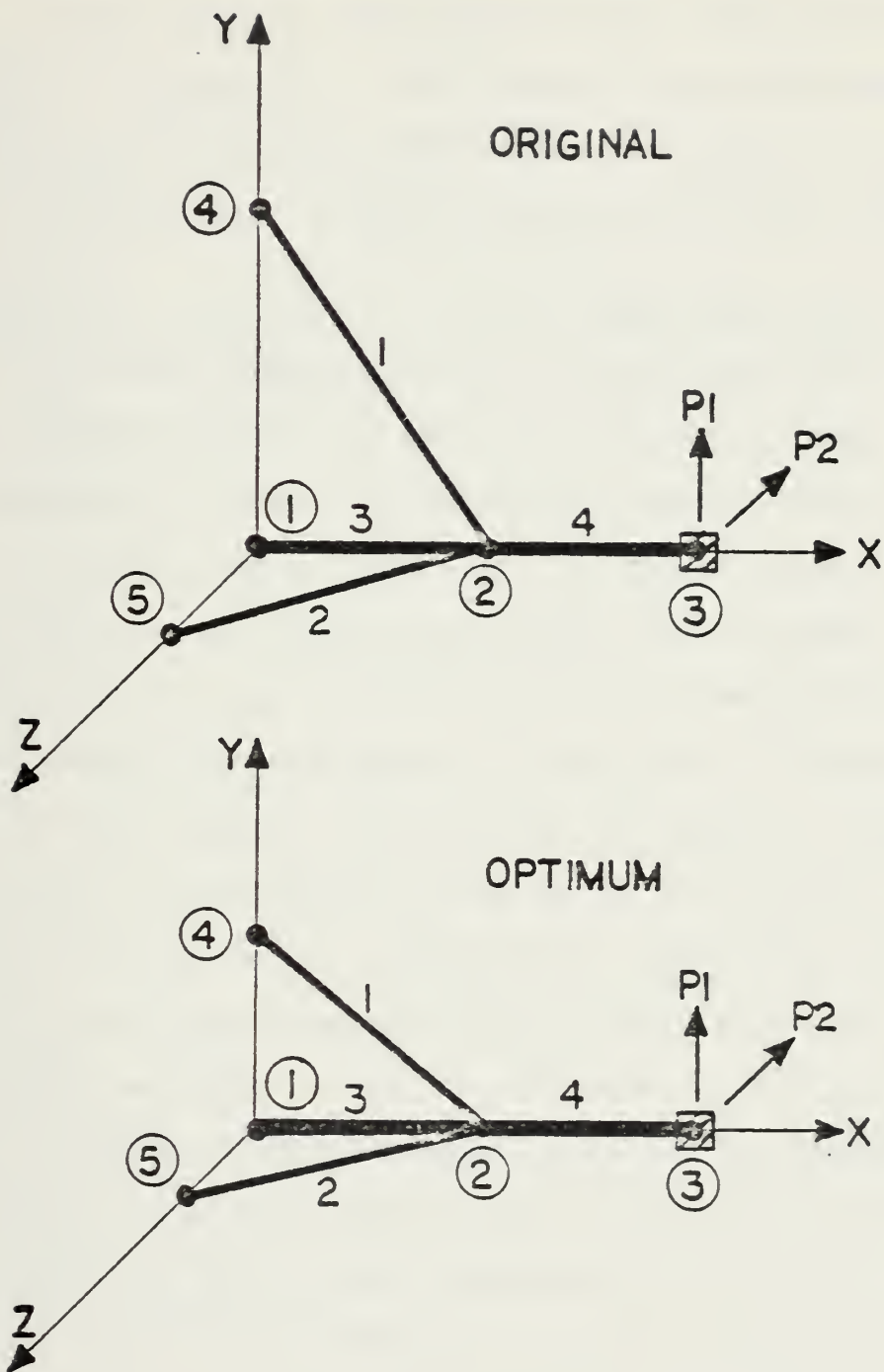


Figure 6.1 TRUSS-BRACED CANTILEVER BEAM





The number of analyses required for this design is 116 using 2.75 seconds of CPU time and terminating on the 12th iteration. Of the analyses conducted, 84 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9542 pounds to 838 pounds. Results are given in Table VII.

#### C. EXAMPLE 2: TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES

The two-tier three-dimensional portal frame with truss member diagonal braces, as shown in Figure 6.2, is a symmetric moderately sized case that can be analyzed easily by a variety of other codes. There are 20 truss elements, 16 frame elements, and four non-structural fixed masses. The material used is steel. This structure is designed for optimum member size and geometry under a set of three load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed masses and the structure's own weight are imposed as loads. There are 10 member size and five coordinate design variables and a total of 493 constraints. The number of analyses required for this design is 385 using 120 seconds of CPU time and terminating on the 21st iteration. Of the analyses conducted, 305 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9302 pounds to 1462 pounds. Results are given in Table VIII.



# TABLE VII

## EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

### FINAL OPTIMIZATION INFORMATION

OBJ = C.5E7507E+C3

THERE ARE 1 ACTIVE CONSTRAINTS  
CONSTRAINT NUMBERS ARE  
36

THERE ARE 0 VIOLATED CONSTRAINTS

THERE ARE 0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION  
ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS = 12

OBJECTIVE FUNCTION WAS EVALUATED 114 TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED 114 TIMES

THIS RUN REQUIRED 116 STRUCTURAL ANALYSES

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 2.79

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS  
WEIGHT= C.5E751E+C3

TOTAL WEIGHT INCLUDING FIXED MASSES  
TOTAL WEIGHT= C.83751E+C3

JCINT	X	Y	Z
1	0.0	0.0	0.0
2	C.10000E+C3	0.0	0.0
3	C.20000E+C3	0.0	0.0
4	0.0	C.84259E+02	0.0
5	0.0	0.0	C.45432E+02

### ELEMENT INFORMATION FOR BAR ELEMENTS

#### ELEMENT-JCINT RELATIONSHIPS

ELEMENT	NODE 1	NODE 2	AREA	LENGTH
1	2	4	C.3481E+C1	C.1308E+03
2	2	5	C.8499E+01	C.1098E+03

### ELEMENT INFORMATION FOR FRAME ELEMENTS

#### ELEMENT-JCINT RELATIONSHIPS

LAC	NODE1	NODE2	AREA	LENGTH	CHAR.DIM.1	CHAR.DIM.2
3	1	2	C.3329E+01	C.1000E+03	C.4839E+01	C.2190E+00
4	1	3	C.2368E+01	C.1000E+03	C.4839E+01	C.1558E+00

### EIGENVALUES AND EIGENVECTORS

MODE NUMBER 1  
FREQUENCY = C.41388E+C2 CPS  
C.26319E+C3 RPS  
EIGENVALUE = C.69270E+05  
EIGENVECTOR = DEGREE OF FREEDOM

JCINT	1	2	3
1	C.0	0.0	0.0
2	0.0	C.0	0.0
3	-C.23435E-01	-C.33985E-01	-C.74537E-01
4	-C.30777E-01	-C.10745E-01	-C.15830E-03
5	-C.23435E-01	-C.17155E-01	C.10000E+01



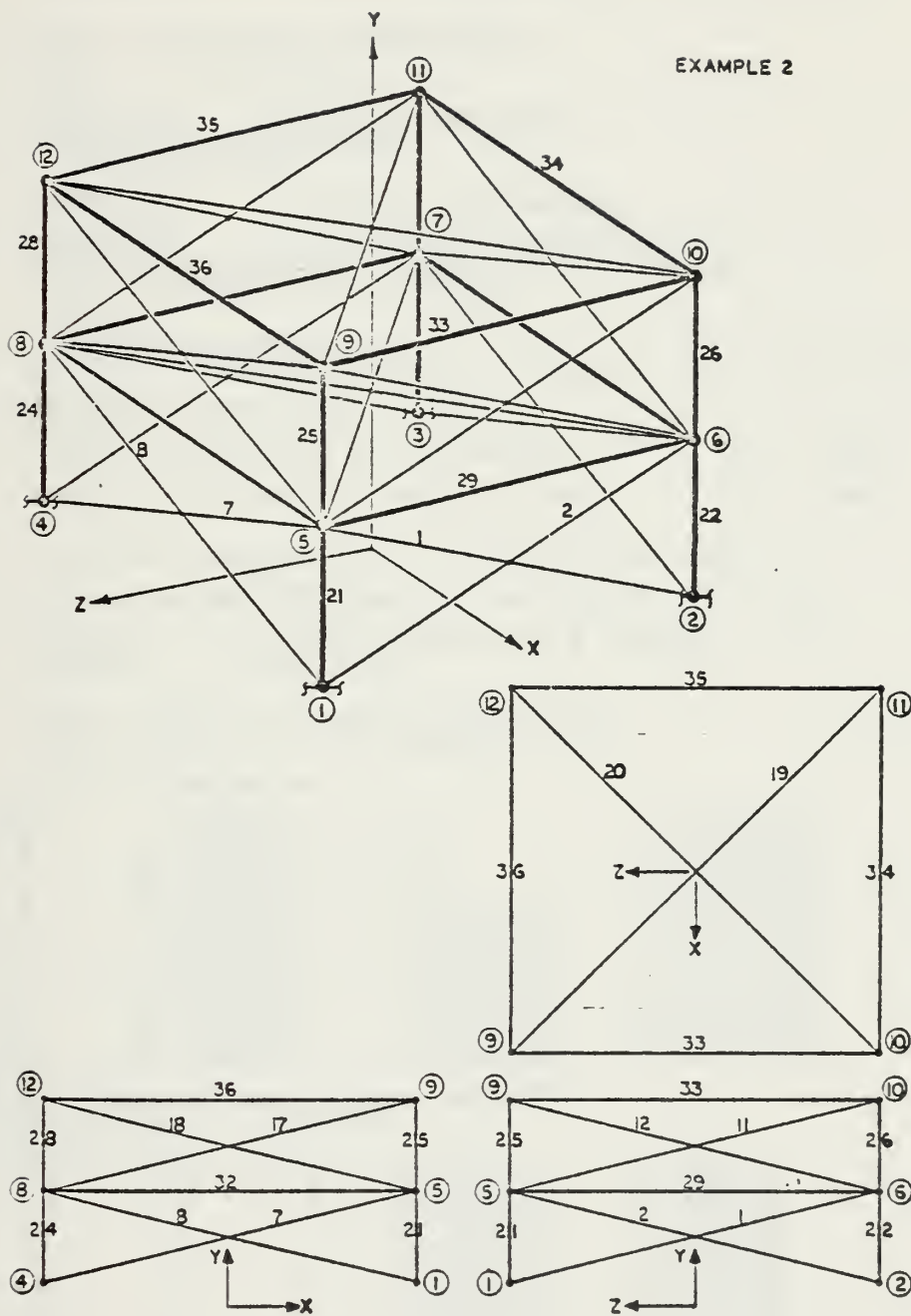


Figure 6.2 TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES





# TABLE VIII

## EXAMPLE 2: FINAL OPTIMIZATION INFORMATION

### FINAL OPTIMIZATION INFORMATION

OBJ = C.144183E+C4

THERE ARE 3 ACTIVE CCNSTRANTS  
CCNSTRANT NUMBERS ARE  
46 91 196

THERE ARE 0 VIOLATED CCNSTRANTS

THERE ARE 1 ACTIVE SIDE CONSTRAINTS  
DECISION VARIABLES AT LOWER OR UPPER BOUNDS  
(MINUS INDICATES LOWER BOUND)  
-14

TERMINATION CRITERION  
ABS(CBJ(I)-CBJ(I-1)) LESS THAN CABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS = 21

OBJECTIVE FUNCTION WAS EVALUATED 383 TIMES

CCNSTRANT FUNCTIONS WERE EVALUATED 383 TIMES

THIS RUN REQUIRED 385 STRUCTURAL ANALYSES

NUMBER OF SECCNDS REQUIRED FOR EXECUTION = 120.7

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS  
WEIGHT= 0.14418E+C4

TOTAL WEIGHT INCLUDING FIXED MASSES  
TOTAL WEIGHT= C.16418E+04

JOINT COORDINATES			
JOINT	X	Y	Z
1	0.63385E+C2	0.0	-0.90002E+02
2	-0.63385E+C2	0.0	-0.90002E+02
3	0.0	0.0	-0.90002E+02
4	-0.63385E+C2	0.0	-0.90002E+02
5	0.63385E+C2	0.20000E+02	-0.69074E+02
6	0.63385E+C2	0.20000E+02	-0.69074E+02
7	-0.63385E+C2	0.20000E+02	-0.69074E+02
8	-0.63385E+C2	0.20000E+02	-0.69074E+02
9	0.10000E+03	0.10000E+03	-0.10000E+03
10	0.10000E+03	0.10000E+03	-0.10000E+03
11	-0.10000E+03	0.10000E+03	-0.10000E+03
12	-0.10000E+03	0.10000E+03	0.10000E+03

### ELEMENT INFORMATION FOR BAR ELEMENTS ELEMENT-JOINT RELATIONSHIPS

ELEMENT	NODE 1	NODE 2	AREA	LENGTH
1	1	5	0.4255E+C0	0.1612E+03
2	2	5	0.4255E+C0	0.1612E+03
3	3	7	0.4255E+C0	0.1469E+03
4	4	6	0.4255E+C0	0.1469E+03
5	5	7	0.4255E+C0	0.1612E+03
6	4	1	0.4255E+C0	0.1612E+03
7	4	5	0.4255E+C0	0.1469E+03
8	5	7	0.4255E+C0	0.1612E+03
9	5	8	0.4255E+C0	0.2118E+03
10	6	10	0.1944E+C1	0.1881E+03
11	6	9	0.1944E+C1	0.1881E+03
12	6	11	0.1944E+C1	0.1996E+03





#### D. EXAMPLE 3: DD-963 FOREMAST

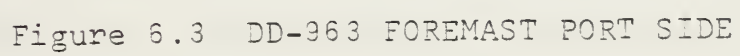
Example three is a redesign of the forward mast on the DD-963 of SPRUANCE class destroyer. The DD-963 foremast has been chosen as the third test case for the following reasons: 1) the structure is typical of the masts found on many combatants in the United States and other navies, 2) high top-side weight reduction is desirable from a stability viewpoint for any ship, 3) the structural members are predominantly tubular, 4) the problem is sufficiently complex to make conventional design methods cumbersome, 5) the member size and loading information is available.

The structure as shown in Figures 6.3 through 6.6 is constructed of 172 aluminum frame members. The material used in the structure is 5086 H32 aluminum, an alloy with moderate strength, good weldability, and good corrosion resistance.

This structure is designed for optimum member size under a single load condition and subject to constraints on maximum member stress, maximum joint displacement, Euler and local buckling.

Some structural simplifications are made. The weights of mast-mounted radars, antennas, and platforms are modeled by a series of fixed masses which are imposed as loads along with the structure's own weight. The forces due to halyards and wire antennas are applied as loads. Inertial forces due to ships motion are calculated for the initial design point







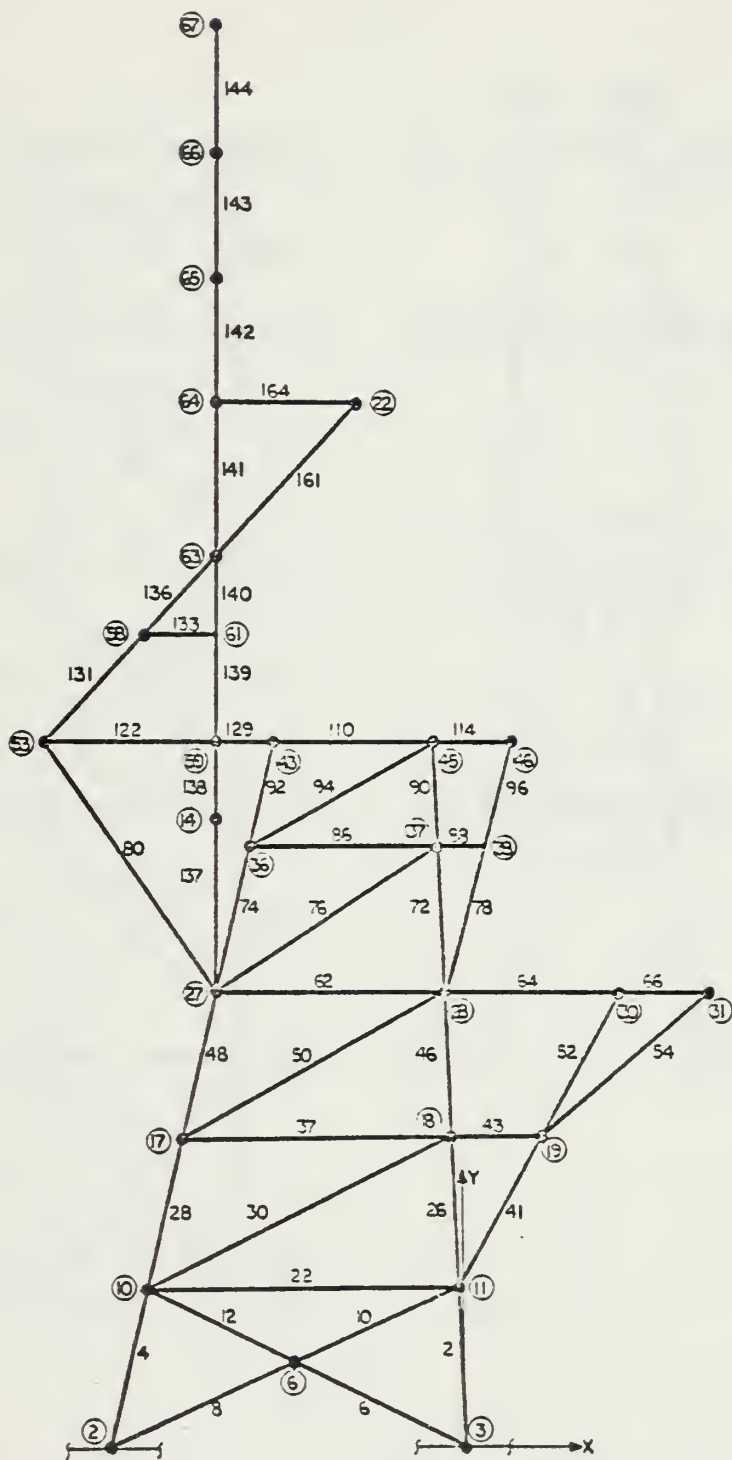


Figure 6.4 DD-963 FOREMAST STARBOARD SIDE



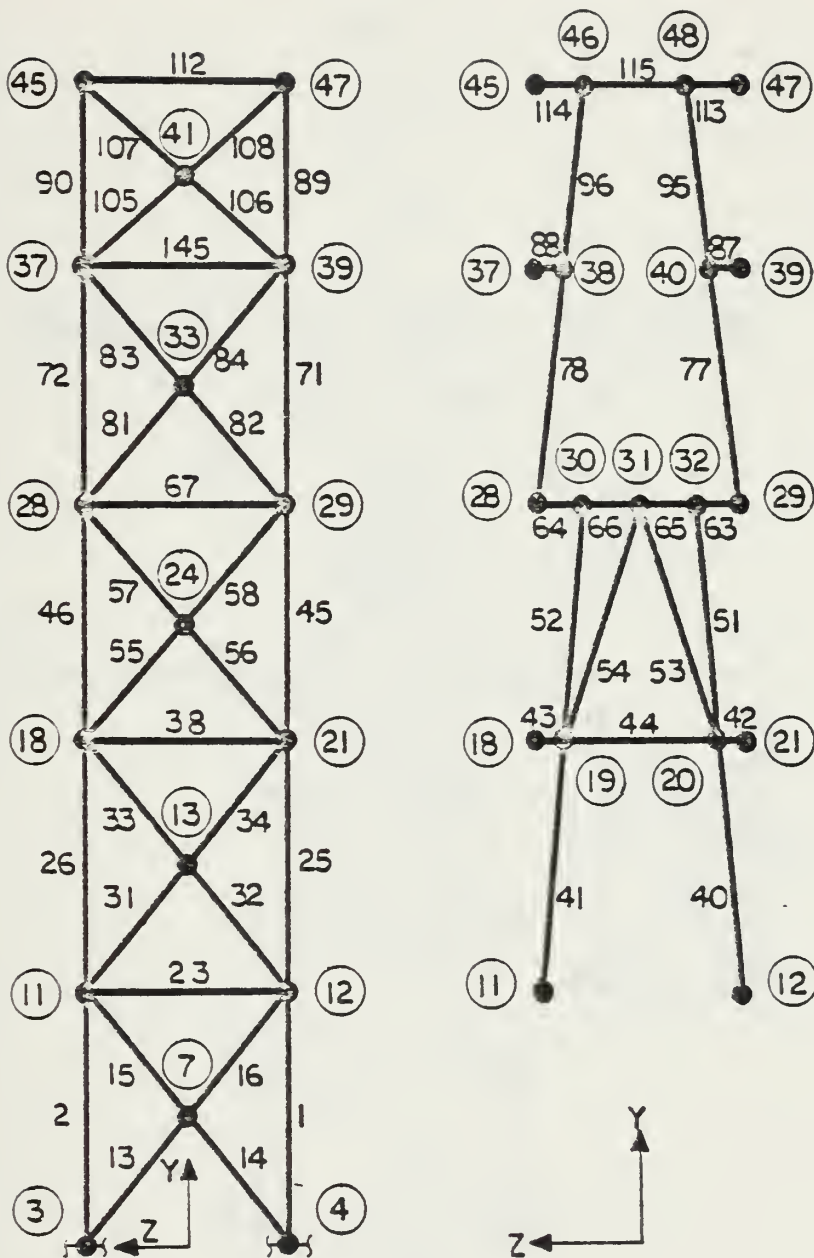


Figure 6.5 DD-963 FOREMAST FORWARD SIDE





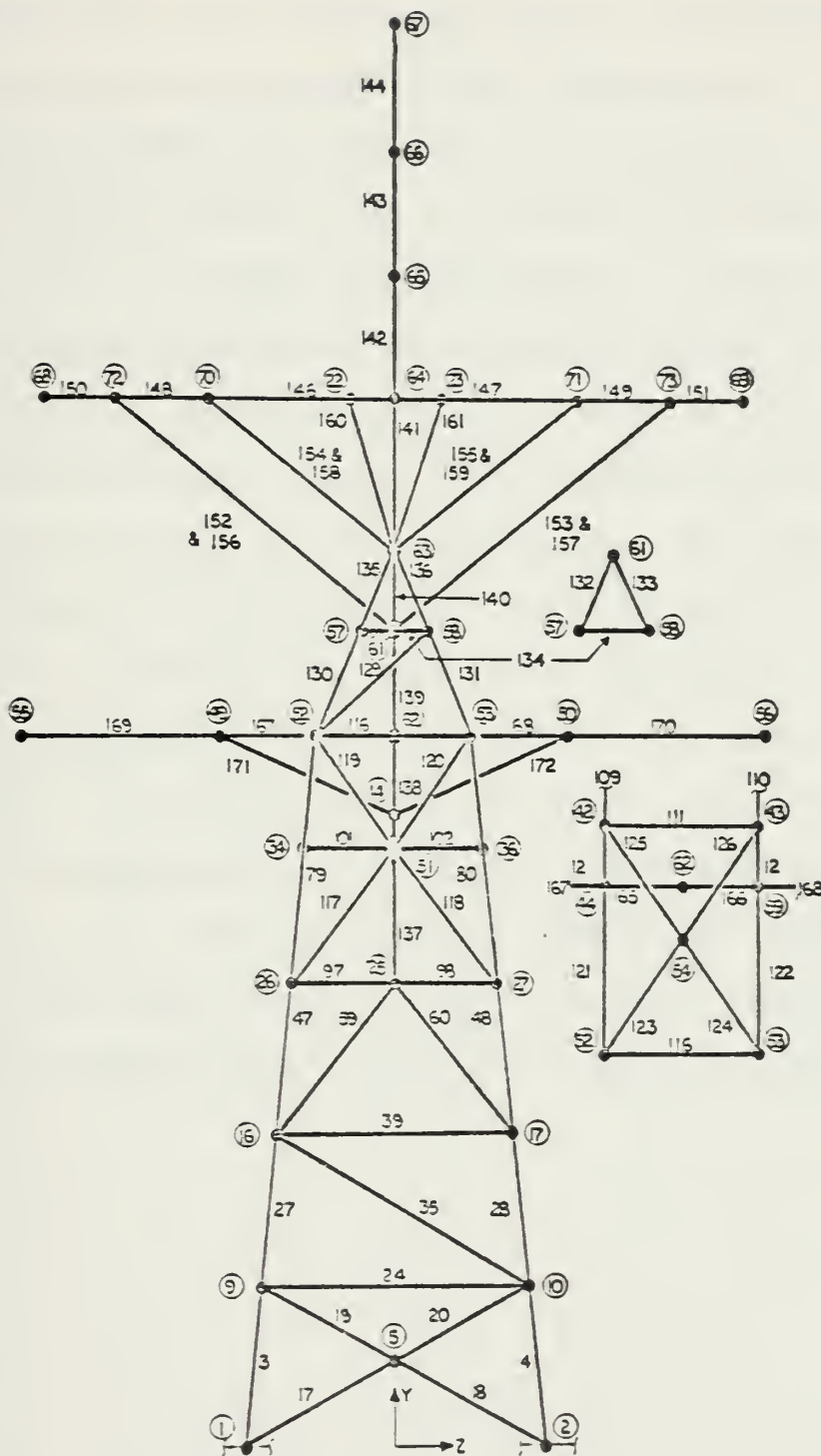


Figure 6.6 DD-963 FOREMAST AFT SIDE



and consist of the product of a member's half-weight and a coordinate-dependent load-factor applied at each end of the element [Ref. 6]. The load-factor multiplier is dependent on the distances from a point at the intersection of the design waterline and the ship centerline amidships (frame 264 1/2). Ship's motion loads are applied for a roll to port. In that the purpose of this example is only to attempt to solve a large and messy problem rather than to produce an actual design no attempt is made to include wind, shock, and blast loads. There are 34 member size design variables and a total of 1064 constraints. The number of analyses required for this design is 555 using 4482 seconds of CPU time and terminating on the 17th iteration. Of the analyses conducted, 544 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is increased from 48,199 pounds to 56,746 pounds. The structure as modeled was initially infeasible due, most likely to the structural simplifications made in the topmast area. Results are given in Table IX.



# TABLE IX

## EXAMPLE 3: FINAL OPTIMIZATION INFORMATION

### FINAL OPTIMIZATION INFORMATION

OBJ = C.398604E+05

THERE ARE 2 ACTIVE CONSTRAINTS  
CONSTRAINT NUMBERS ARE  
860 866

THERE ARE 0 VIOLATED CONSTRAINTS

THERE ARE 0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION  
ABS(OBJ(I))-OBJ(I-1) LESS THAN CABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS = 17

OBJECTIVE FUNCTION WAS EVALUATED 553 TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED 553 TIMES

THIS RUN REQUIRED 555 STRUCTURAL ANALYSES

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS  
WEIGHT= 0.29860E+05

TOTAL WEIGHT INCLUDING FIXED MASSES  
TOTAL WEIGHT= 0.56746E+05

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 4482.46

NO. OF FRAME ELEMENTS = 172  
ELEMENT-JOINT RELATIONSHIPS

LNO	NCCE1	NCCE2	AREA	LENGTH	CHAR.DIM.1	CHAR.DIM.2
1	4	12	0.5979E+02	0.1081E+03	C.1900E+02	0.1002E+01
2	3	11	0.5979E+02	0.1081E+03	C.1900E+02	0.1002E+01
3	1	9	0.5979E+02	0.1112E+03	C.1900E+02	0.1002E+01
4	2	10	0.5979E+02	0.1112E+03	C.1900E+02	0.1002E+01
5	4	8	0.6247E+01	0.1342E+03	C.6563E+01	0.3030E+00
6	3	6	0.6247E+01	0.1342E+03	C.6563E+01	0.3030E+00
7	1	8	0.6247E+01	0.1369E+03	C.6563E+01	0.3030E+00
8	2	6	0.6247E+01	0.1369E+03	C.6563E+01	0.3030E+00
9	8	12	0.6247E+01	0.1295E+03	C.6563E+01	0.3030E+00
10	6	11	0.6247E+01	0.1295E+03	C.6563E+01	0.3030E+00
11	8	9	0.6247E+01	0.1132E+03	C.6563E+01	0.3030E+00
12	6	10	0.6247E+01	0.1132E+03	C.6563E+01	0.3030E+00
13	3	7	0.6247E+01	0.6846E+02	C.6563E+01	0.3030E+00
14	4	7	0.6247E+01	0.6846E+02	C.6563E+01	0.3030E+00
15	7	11	0.6247E+01	0.6846E+02	C.6563E+01	0.3030E+00
16	7	12	0.6247E+01	0.6846E+02	C.6563E+01	0.3030E+00
17	1	9	0.6247E+01	0.1196E+03	C.6563E+01	0.3030E+00
18	2	6	0.6247E+01	0.1196E+03	C.6563E+01	0.3030E+00
19	5	9	0.6247E+01	0.1097E+03	C.6563E+01	0.3030E+00
20	5	10	0.6247E+01	0.1097E+03	C.6563E+01	0.3030E+00
21	9	12	0.6247E+01	0.2172E+03	C.6563E+01	0.3030E+00
22	10	11	0.6247E+01	0.2172E+03	C.6563E+01	0.3030E+00
23	11	12	0.6247E+01	0.8400E+02	C.6563E+01	0.3030E+00
24	9	10	0.6247E+01	0.1899E+03	C.6563E+01	0.3030E+00
25	12	11	0.5979E+02	0.1081E+03	C.1900E+02	0.1002E+01
26	11	9	0.5979E+02	0.1081E+03	C.1900E+02	0.1002E+01
27	9	10	0.5979E+02	0.1111E+03	C.1900E+02	0.1002E+01
28	10	17	0.5979E+02	0.1111E+03	C.1900E+02	0.1002E+01
29	9	11	0.7358E+01	0.2380E+03	0.7767E+01	0.3016E+00
30	10	18	0.7358E+01	0.2380E+03	0.7767E+01	0.3016E+00
31	11	13	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00
32	12	13	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00











## VII. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

An existing finite element code was expanded to encompass the more general case of frame members; i.e., six degrees of freedom per joint. Combined truss and frame structures were designed for minimum weight with multiple load conditions considered.

The displacement method was used for static analysis and the subspace iteration method was used for eigenvalues.

Several examples were considered. In every case the code worked as an analysis tool, and significant weight reductions were obtained with the coupled optimizer CONMIN.

The SADX design code has been shown to be a useful tool for ship mast optimum design.

### B. RECOMMENDATIONS

The following recommendations may be of value for future work.

1. The routines necessary to calculate gradients analytically should be added to the code.
2. The code should be extended to include plate and shear elements and a library of member cross-sections.
3. An out of core equation solver should be added.



4. The ability to specify multipliers for applying inertial loads along the three coordinate axes should be added in a fashion similar to that used for applying structure's own weight as loads. Such an addition would simplify dynamic load analysis and design.

5. The method of gradient calculation should be dependent on specific gradients required [Ref. 7] and [Ref. 3].

6. Gradients of frequency constraints would benefit from a more efficient algorithm [Ref. 9].

7. The need for a large scale public structural optimization code still exists.

8. The code should be modified to allow optimum member size design followed by simultaneous optimum member size and optimum geometry design.



## LIST OF REFERENCES

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## APPENDIX A

### DATA FILES

#### A. INTRODUCTION

This appendix contains the data files used to create the test cases in Chapter VI. Additionally the data file for the USER'S guide in complete form is presented.





TABLE X

## DATA FILE TRUSS-BRACED CANTILEVER BEAM

```

*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK A TITLE 1 CARD FORMAT 80H
TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK B CONTROL PARAMETERS 3 CARDS FORMAT 8I10
$ NEB 1 NEF 2 NJ 3 NCJ 4 NMT 5 IOVCLC 6 NDJ 7
$ NEUBC 2 LBUCK 2 NFREQ 5 NFMAS 3 NEIG 2 NEIG1 2 NPRI 2
$ NLC 1 NDSPLC 1 NSTRES 1 NSTW 1 NFMW 1 2 0
$ 2 2 2 1 1 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK C DYNAMIC ANALYSIS INFORMATION 1 CARD FORMAT 110,2F10.0
$ LMASS 1 GRAV 2 SPSEIG 3
$ 0 386.4 0
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK D JOINT COORDINATES 5 *****6*****7*****
$ NJ CAPOS FORMAT 110,3F10
$ JN 1 X-COORD 1 Y-COORD 1 Z-COORD 1
$ 1 0. 0. 0.
$ 2 100. 0. 0.
$ 3 200. 0. 0.
$ 4 0. 150. 0.
$ 5 0. 0. 50.
$BLOCK E DESIGN VARIABLE LINKING DATA 4I10,3F10.0
$ NDJ CARDS 1 IX 2 IY 3 IZ 4 PCX 5 PCY 6 PCZ 7
$ 1 0 0 0 1.0 1.0 1.0
$ 2 0 0 0 1.0 1.0 1.0
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK F MATERIAL PROPERTIES 6F10.0
$ E 1 RFC 2 SIGMIN 3 SIGMAX 4 NMT CARDS 5 KEULER 6 POISSN 7
$ 1.0E+7 0. 25000. 25000. 2. .27
$ 2.5E+7 0.3 -36000. 36000. 2. .27
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK G BAR ELEMENT INFORMATION 5I10,F10,I10
$ LNO 1 NCCE2 2 NCCE3 3 MATCOD 4 NSDG1 5 AREA 6 LSECT 7
$ 1 1 2 1 1 3.0 1
$ 2 1 2 2 1 2 3.0 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK H FRAME ELEMENT INFORMATION 2*NEF CARDS FORMAT 7I10/2F10
$ LNO 1 NCCE2 2 NCCE3 3 MATCOD 4 NSDG1 5 NSDG2 6 LSECT 7
$ 1 1 2 2 3 4 1
$ CHARDIM1 CHARDIM2
$ 1 5.0 1.0
$ 2 5.0 1.0
$ 3 3 2 3 5 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK I JOINT CONSTRAINT DATA 7I10
$ JN 1 IX 2 IY 3 IZ 4 IXX 5 IYY 6 IZZ 7
$ 1 1 1 1 1 1 1
$ 2 0 0 0 0 0 0
$ 3 0 0 0 0 0 0
$ 4 1 1 1 1 1 1
$ 5 1 1 1 1 1 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK J JOINT LOADING DATA 1 CARD FORMAT I10
$ (CMT IF NLC=C IN BLOCK B)
$ NLJ 1

```



TABLE XI

## DATA FILE TRUSS-BRACED CANTILEVER BEAM continued

```

$      JN      FX      FY      FZ      NLJ CARDS      FORMAT I10,6F10
$      3      0.      1000.0      0.      0.      0.      0.
$      3      0.      0.0      -1000.0      0.      0.      0.
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK K FIXED MASS DATA      NFMAS CARDS      FORMAT I10,F10.0
$      (CMIT IF NFMAS=0 IN BLOCK B)
$      JN      MASS
$      3      250.0
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK L DESIGN VARIABLE INFORMATION CARDS AS REQ'D      FORMAT 8F10.0
$      (AREA AND DIMENSION VARIABLES      CMIT IF NDVAP1=0)
$      XA(I) . . . XA(NDVAR1)
$      20.0      20.0      2.0      2.0      |      |
$      XAL(I)      20.0      20.0      2.0      2.0      |      |
$      .50      .50      .10      .10      |      |
$      XAU(I)      25.0      35.0      2.5      4.0      |      |
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK M DESIGN VARIABLE INFORMATION CARDS AS REQ'D      FORMAT 8F10.0
$      (COORDINATE VARIABLES      CMIT IF NDVAR2=0)
$      XC(I) . . . XC(NDVAR2)
$      150.0      50.0      |      |      |      |
$      XCL(I)      0.0      0.0      |      |      |      |
$      XCU(I)      200.0      100.0      |      |      |      |
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS      NDSPLC CARDS      FORMAT 3I10,2F10
$      (CMIT IF NDSPLC=C IN BLOCK B)
$      JN      CIR      LC      BL      BU
$      3      3      2      1      1
$      3      3      2      -3.0      3.0
$      3      3      2      -3.5      3.5
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK O FREQUENCY CONSTRAINTS      NO. OF CARDS AS REQ'D      FORMAT 8F10.0
$      (CMIT IF NREQ=0 IN BLOCK B)
$      FC1 . . . FCN
$      1.0      |      |      |      |      |
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK P END CARD
$      END

```



TABLE XII

## DATA FILE TWO-TIER 3-D PORTAL FRAME

```

*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK A TITLE 1 CARD FORMAT 80H
2-TIER FRAME STRUCTURE WITH TRUSS X-BRACES: EXAMPLE 2
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK B CONTROL PARAMETERS 3 CARDS FORMAT 8I10
$ NEB NEF NJ NCJ NMT IDVCLC NDJ
$
$ NEUBC 20 LBLOCK 16 NFREQ 12 NFMAS 8 NEIG 1 NEIG1 2 NPRI 8
$
$ NLC 1 NDSFLC 1 NSTRES 1 NSTW 4 NFMW 3
$
$ 3 12 2 1 1
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK C DYNAMIC ANALYSIS INFORMATION 1 CARD FORMAT 110,2F10.0
$ LMASS GRIV EPSEIG
$
$ 0 386.4 0.
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK D JOINT COORDINATES
$ NJ CARDS FORMAT 110,3F10
$ JN X-COORD Y-COORD Z-COORD
$
$ 1 100. 0. 100.
$ 2 100. 0. -100.
$ 3 -100. 0. -100.
$ 4 -100. 0. 100.
$ 5 100. 50. 100.
$ 6 100. 50. -100.
$ 7 -100. 50. -100.
$ 8 -100. 50. 100.
$ 9 100. 100. 100.
$ 10 100. 100. -100.
$ 11 -100. 100. -100.
$ 12 -100. 100. 100.
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK E DESIGN VARIABLE LINKING DATA
$ NDJ CARDS FORMAT 4I10,3F10.0
$ JN IY IZ PCX PCY PCZ
$
$ 1 1 0 1 0.0 0.0 1.0
$ 2 1 0 2 -1.0 0.0 -1.0
$ 3 1 0 2 -1.0 0.0 -1.0
$ 4 1 0 2 -1.0 0.0 1.0
$ 5 4 4 5 1.0 1.0 1.0
$ 6 4 4 5 1.0 1.0 -1.0
$ 7 4 4 5 -1.0 1.0 -1.0
$ 8 4 4 5 -1.0 1.0 1.0
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK F MATERIAL PROPERTIES NMT CARDS FORMAT 6F10.0
$ E RFC SIGMIN SIGMAX KEULER POISSN
$
$ 2.9E+7 0.3 -42000. 36000. 4. .27
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK G BAR ELEMENT INFORMATION NEB CARDS FORMAT 5I10,F10,I10
$ LNG NOE2 NCDE3 MATCOD NSDG1 AREA LSECT
$
$ 1 1 6 1 1 5.0 1
2,5,2,1,1,1,5,0,1
3,2,7,1,1,1,5,0,1
4,6,3,1,1,1,5,0,1
5,3,8,1,1,1,5,0,1
6,7,4,1,1,1,5,0,1
7,4,5,1,1,1,5,0,1
8,1,8,1,1,1,5,0,1
9,5,7,1,1,1,5,0,1
10,6,8,1,1,1,5,0,1
11,5,10,1,2,5,C,1
12,6,9,1,2,5,C,1
13,6,11,1,2,5,C,1
14,7,10,1,2,5,C,1

```





# TABLE XIII

## DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```

15,7,12,1,2,5.C,1
16,8,11,1,2,5.C,1
17,8,9,1,2,5.0,1
18,5,12,1,2,5.C,1
19,9,11,1,2,5.C,1
20,10,12,1,2,5.0,1
*****2*****3*****4*****5*****6*****7*****
$BLOCK H FRAME ELEMENT INFORMATION 2*NEF CARDS FORMAT 7I10/2F10
$ LNC NOCE2 NCDE3 MATCOC NSDG1 NSDG2 LSECT
21,1,5,1,3,4,1 0.50
22,2,6,1,3,4,1 0.50
23,3,7,1,3,4,1 0.50
24,4,8,1,3,4,1 0.50
25,5,9,1,5,6,1 0.50
26,6,10,1,5,6,1 0.50
27,7,11,1,5,6,1 0.50
28,8,12,1,5,6,1 0.50
29,5,6,1,7,8,1 0.50
30,6,7,1,7,8,1 0.50
31,7,8,1,7,8,1 0.50
32,8,5,1,7,8,1 0.50
33,9,10,1,9,10,1 0.50
34,10,11,1,9,10,1 0.50
35,11,1,1,9,10,1 0.50
36,12,5,1,9,10,1 0.50
*****2*****3*****4*****5*****6*****7*****
$BLOCK I JOINT CONSTRAINT DATA NCJ CARDS FORMAT 7I10
$ JN IX IY IZ IXX IYY IZZ
1,1,1,1,1,1,1
2,1,1,1,1,1,1
3,1,1,1,1,1,1
4,1,1,1,1,1,1
5,
6,
7,
8,
9,
10,
11,
12,
*****2*****3*****4*****5*****6*****7*****
$BLOCK J JOINT LOADING DATA 1 CARD FORMAT I10
$ (CMIT IF NLC=0 IN BLOCK B)
$ NLJ
2,
$ JN FX FY FZ NLJ CARDS FORMAT I10,6F10
$ TX TY TZ
5,1000.
10,1000.
4,
5,500.
10,500.

```





# TABLE XIV

## DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```

5,-500.
6,-500.
4,
10,1000.
5,C.C.C.C,1000.
12,-1000.
11,C.O.O.C,-1000.
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK K FIX SEC MASS DATA NFMAS CARDS FORMAT 11C,F10.0
$ (CMIT IF NFMAS=0 IN BLOCK 8)
$ JN MASS
$
$ 50.C
10,50.C
11,50.C
12,50.C
*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK L DESIGN VARIABLE INFORMATION CARDS AS REQ'D FORMAT 8F10.0
$ (AREA AND DIMENSION VARIABLES CMIT IF NDVAR1=0)
$ XA(1) . . . XA(NDVAR1)
$
$ 3.5 3.5 5.0 0.5 5.0 0.5 5.0 0.5
$ XAL(1) 0.5
$
$ 0.1 0.1 .50 0.1 .50 0.1 .50 0.1
$ XAU(1) 0.1
$
$ 30.0 30.0 30.0 .50 30.0 .50 30.0 0.5
$ XC(1) . . . XC(NDVAR2)
$
$ 100.0 100.0 100.0 100.0 50.0 | |
$ XCL(1) | |
$
$ 20.0 20.0 20.0 20.0 20.0 | |
$ XCU(1) | |
$
$ 160.0 160.0 160.0 160.0 80.0 | |
$*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS NDSPLC CARDS FORMAT 3I10,2F10
$ (CMIT IF NDSPLC=0 IN BLOCK 8)
$ JN DIR LC BL BU
$
$ 9 1 1 1 5.0 5.0
10 1 1 1 5.0 5.0
11 1 1 1 5.0 5.0
12 1 1 1 5.0 5.0
9 1 1 1 5.0 5.0
10 1 1 1 5.0 5.0
11 1 1 1 5.0 5.0
12 1 1 1 5.0 5.0
9 1 1 1 5.0 5.0
10 1 1 1 5.0 5.0
11 1 1 1 5.0 5.0
12 1 1 1 5.0 5.0
$*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK C FREQUENCY CONSTRAINTS NO. OF CARDS AS REQ'D FORMAT 8F10.0
$ (CMIT IF NFREQ=0 IN BLOCK 8)
$ FC1 . . FCN
$
$ 1.0 5.0 10.0 | | | |
$*****1*****2*****3*****4*****5*****6*****7*****
$BLOCK F END CARD
END

```



TABLE XV

## DATA FILE DD-963 FOREMAST

```

$BLOCK A TITLE
DD-963 CLASS DESTROYER FORWARD MAST REDESIGN: EXAMPLE 1
$ THIS IS A SIMPLIFICATION OF THE ACTUAL STRUCTURE AND LOADS BASED ON
$ NAVSHIPS DRAWING NUMBER 128-4535510 AND NAVSHIPS SKETCH NUMBER
$ 80064-128-SK45879
$ THIS ANALYSIS REQUIRES A THE X-AXIS FORWARD, Y-AXIS UP, AND Z-AXIS
$ TO STBD; A DIFFERENT ORIENTATION THAN IN THE ABOVE DRAWINGS
$BLOCK B CONTROL PARAMETERS
$ NEB      NEF      NJ      NCJ      NMT      IDVCLC      NDJ
$          |        |        |        |        |        |        |
$ NEUBC    0      LBLOCK 172    NFREQ 73    NFMAS 20    NEIG 1      NEIG1 1    NPRI 0
$          |        |        |        |        |        |        |
$ NLC      1      NDSFLC 1      NSTRES 0    NSTW 33    NFMW 0      0      0
$          |        |        |        |        |        |        |
$          1      1      2      1      1      1      1
*****2*****3*****4*****5*****6*****7***
$BLOCK C DYNAMIC ANALYSIS INFORMATION
$ NOCE 15 IS AN UNCONNECTED FIXED DUMMY NODE
$          15      16      17      18      19      20      21      22      23      24      25      26      27      28      29      30      31      32      33      34      35      36      37      38      39      40      41      42      43      44      45      46      47      48
$          0.1      -192.6      -192.6      -10.56      34.00      54.00      -10.56      -172.00      -172.00      -13.22      -168.88      -168.88      -168.88      -15.84      -15.84      108.00      168.00      108.00      -18.12      -147.88      -147.88      -147.88      -20.44      12.00      -20.44      12.00      -22.22      -132.00      -132.00      -172.00      -24.00      30.00      -24.00      20.00
$          0.00      216.00      216.00      216.00      216.00      216.00      216.00      736.00      736.00      270.00      324.00      324.00      324.00      324.00      324.00      324.00      324.00      324.00      372.00      420.00      420.00      420.00      420.00      420.00      420.00      420.00      456.00      492.00      492.00      492.00      492.00      492.00      492.00
$          0.00      -83.16      83.16      42.00      42.00      -42.00      -42.00      -18.00      18.00      0.00      0.00      -71.76      71.76      42.00      -42.00      48.00      0.00      -48.00      0.00      -61.68      0.00      61.68      42.00      39.00      -42.00      -39.00      0.00      -54.00      -54.00      -54.00      42.00      36.00      -42.00      -36.00
$ END NOCES FOR THE LOWER QUADRAPOD OF THE FORWARD MAST
$ START THE UPPER FOREMAST NODES

```



## TABLE XVI

DATA FILE DD-963 FOREMAST continued

```

49      -172.0      492.0      -120.0
50      -172.0      492.0      120.0
51      -228.0      408.0      0.0
52      -228.0      492.0      -56.0
53      -228.0      492.0      56.0
54      -240.0      492.0      0.0
55      -172.0      492.0      -276.0
56      -172.0      492.0      276.0
57      -218.0      600.0      -24.0
58      -218.0      600.0      24.0
59      -172.0      492.0      54.0
$ NODE 6C IS AN UNCONNECTED FIXED CUMMY NOCE
60      0.0      0.0      0.0
61      -172.0      600.0      0.0
62      -172.0      492.0      0.0
63      -172.0      664.0      0.0
64      -172.0      736.0      0.0
65      -172.0      896.0      0.0
66      -172.0      576.0      0.0
67      -172.0      1056.0      0.0
68      -172.0      736.0      -264.0
69      -172.0      736.0      264.0
70      -172.0      736.0      -156.0
71      -172.0      736.0      156.0
72      -172.0      736.0      -228.0
73      -172.0      736.0      228.0
*****1*****2*****3*****4*****5*****6*****7***
$BLOCK MATERIAL INFORMATION
2. SE 7 0.1 -42000. 42000. 4. .27
*****1*****2*****3*****4*****5*****6*****7***
$BLOCK G BAR ELEMENT INFORMATION NEB CARDS FORMAT 5110,F10,I10
$ LNC NCCE2 NCCE3 MATCOG NSCG1 AREA LSECT
$
*****1*****2*****3*****4*****5*****6*****7***
$BLOCK FRAME ELEMENT INFORMATION
$ START FRAME ELEMENTS FOR 1ST CR LOWEST TIER OF QUADRAPOC
11.75 .75 11 1 1 2 1
11.75 .75 9 1 1 2 1
11.75 .75 10 1 1 2 1
11.75 .75 8 1 3 4 1
7.625 .375 6 1 3 4 1
7.625 .375 8 1 3 4 1
7.625 .375 6 1 3 4 1
7.625 .375 12 1 3 4 1
7.625 .375 11 1 3 4 1
7.625 .375 9 1 3 4 1
7.625 .375 10 1 3 4 1
7.625 .375 7 1 3 4 1
7.625 .375 7 1 3 4 1
7.625 .375 11 1 3 4 1
7.625 .375 12 1 3 4 1
7.625 .375 5 1 3 4 1
7.625 .375 5 1 3 4 1

```



TABLE XVII

DATA FILE DD-963 FORECAST continued

7.6225	.375	9	1	3	4	1
7.6225	.375	10	1	3	4	1
7.6225	.375	9	1	3	4	1
7.6225	.375	10	1	3	4	1
7.6225	.375	12	1	3	4	1
7.6225	.375	10	1	3	4	1
S END 1ST TIER CF QUADRAPOC START 2ND TIER						
11.75	.75	21	1	1	2	1
11.75	.75	18	1	1	2	1
11.75	.75	16	1	1	2	1
11.75	.75	17	1	1	2	1
7.6225	.375	21	1	5	6	1
7.6225	.375	18	1	5	6	1
7.6225	.375	13	1	5	6	1
7.6225	.375	13	1	5	6	1
7.6225	.375	18	1	5	6	1
7.6225	.375	21	1	5	6	1
7.6225	.375	16	1	5	6	1
7.6225	.375	16	1	7	8	1
7.6225	.375	18	1	7	8	1
7.6225	.375	21	1	7	8	1
7.6225	.375	17	1	7	8	1
7.6225	.375	20	1	7	9	1
11.6225	.375	19	1	7	9	1
11.6225	.375	21	1	7	8	1
7.6225	.375	19	1	7	8	1
7.6225	.375	20	1	7	8	1
S END 2ND TIER OF THE QUADRAPOC START THE 3RD TIER						
11.75	.75	29	1	1	2	1
11.75	.75	28	1	1	2	1
11.75	.75	26	1	1	2	1
11.75	.75	27	1	1	2	1
7.6225	.375	29	1	9	10	1
7.6225	.375	28	1	9	10	1
11.6225	.375	32	1	7	8	1
11.6225	.375	30	1	7	8	1
7.6225	.375	31	1	9	10	1





TABLE XVIII

DATA FILE DD-963 FOREMAST continued

7.6254	.37519	31	1	9	10	1
7.6255	.37518	24	1	9	10	1
7.6256	.37521	24	1	9	10	1
7.6257	.37524	28	1	9	10	1
7.6258	.37524	29	1	9	10	1
7.6259	.37516	25	1	9	10	1
11.6000	.17517	25	1	9	10	1
11.6000	.50000	\$ MEMBERS 61 THRU 70 MODEL THE SPQ-9 PLATFORM ALONG WITH A FIXED MASS				
11.6000	.26029	29	1	11	12	1
11.6000	.27028	28	1	11	12	1
11.6000	.50032	32	1	11	12	1
11.6000	.50030	30	1	11	12	1
11.6000	.50031	32	1	11	12	1
11.6000	.50031	30	1	11	12	1
11.6000	.50029	29	1	11	12	1
11.6000	.50015	60	1	0	0	1
11.6000	.00015	60	1	0	0	1
11.6000	.00015	32	1	11	12	1
11.6000	.50030	\$ END THE 3RD TIER OF THE QUADRAPOD START THE 4TH TIER				
11.7150	.29039	39	1	1	2	1
11.7150	.29037	37	1	1	2	1
11.7150	.29034	34	1	1	2	1
11.7150	.29036	36	1	1	2	1
11.7150	.29039	39	1	13	14	1
7.62576	.37527	37	1	13	14	1
7.62577	.37529	40	1	13	14	1
7.62578	.37528	38	1	13	14	1
7.62579	.37526	52	1	13	14	1
7.62580	.37527	53	1	13	14	1
7.62581	.37528	33	1	13	14	1
7.62582	.37529	33	1	13	14	1
7.62583	.37537	37	1	13	14	1
7.62584	.37539	39	1	13	14	1
7.62585	.37539	39	1	13	14	1
7.62586	.37537	37	1	13	14	1
7.62587	.37540	40	1	13	14	1
7.62588	.37538	38	1	13	14	1



## TABLE XIX

## DATA FILE DD-963 FOREMAST continued

7.6225	.375					
124	53	54	1	15	16	1
7.6225	.375					
124	42	54	1	15	16	1
7.6225	.375					
126	43	54	1	15	16	1
7.6225	.375					
127	42	44	1	15	16	1
7.6225	.375					
128	43	59	1	15	16	1
7.6225	.375					
\$ ENC THE LOWER QUADRAPOD START THE TOPMAST MEMBERS	52	58	1	17	18	1
7.6225	.375					
130	52	57	1	17	18	1
7.6225	.375					
131	53	58	1	17	18	1
7.6225	.375					
132	57	61	1	17	18	1
7.6225	.375					
133	58	61	1	17	18	1
7.6225	.375					
134	57	58	1	17	18	1
7.6225	.375					
135	57	63	1	17	18	1
7.6225	.375					
136	58	63	1	17	18	1
7.6225	.375					
137	14	25	1	19	20	1
23.00	1.5					
138	14	62	1	19	20	1
23.00	1.5					
139	62	61	1	19	20	1
23.00	1.5					
140	61	63	1	19	20	1
23.00	1.5					
141	63	64	1	19	20	1
23.00	1.5					
142	64	65	1	21	22	1
9.50	.50					
143	65	66	1	21	22	1
9.50	.50					
144	66	67	1	21	22	1
9.50	.50					
145	67	39	1	13	14	1
7.6225	.375					
\$ UPPER YARDARMS ANC BRACES	64	70	1	23	24	1
146	.75					
147	64	71	1	23	24	1
148	.75					
149	70	72	1	25	26	1
150	.50					
151	71	73	1	25	26	1
152	.50					
153	72	68	1	25	26	1
154	.50					
155	73	69	1	25	26	1
156	.50					
157	61	72	1	27	28	1
7.6225	.375					
158	61	73	1	27	28	1
7.6225	.375					
159	63	70	1	29	30	1
160	.25					
161	63	71	1	29	30	1
162	.25					
163	61	72	1	27	28	1
7.6225	.375					
164	61	73	1	27	28	1
7.6225	.375					
165	63	70	1	29	30	1



TABLE XX

DATA FILE DD-983 FORECAST continued

7.625	3.75	4TH TIER	CF THE QUADRAPOD START	THE 5TH TIER		
\$ END TIER						
11.75	.375	47	1	1	2	1
11.75	.375	45	1	1	2	1
11.75	.375	42	1	1	2	1
11.75	.375	43	1	1	2	1
11.75	.375	47	1	15	16	1
7.625	.375	45	1	15	16	1
7.625	.375	48	1	13	14	1
7.625	.375	46	1	13	14	1
7.625	.375	26	1	13	14	1
7.625	.375	27	1	13	14	1
7.625	.375	25	1	13	14	1
7.625	.375	35	1	13	14	1
7.625	.375	35	1	13	14	1
7.625	.375	36	1	13	14	1
7.625	.375	42	1	13	14	1
7.625	.375	43	1	13	14	1
7.625	.375	41	1	13	14	1
7.625	.375	41	1	13	14	1
7.625	.375	45	1	13	14	1
7.625	.375	47	1	13	14	1
\$ MEMBERS	109 THRU	128 MODEL THE	SPG-60	PLATFORM ALONG WITH A	FIXED MASS	
7.625	.375	47	1	15	16	1
7.625	.375	45	1	15	16	1
7.625	.375	43	1	15	16	1
7.625	.375	47	1	15	16	1
7.625	.375	47	1	15	16	1
7.625	.375	46	1	15	16	1
7.625	.375	46	1	15	16	1
7.625	.375	53	1	15	16	1
7.625	.375	51	1	13	14	1
7.625	.375	51	1	13	14	1
7.625	.375	51	1	13	14	1
7.625	.375	51	1	13	14	1
7.625	.375	52	1	15	16	1
7.625	.375	59	1	15	16	1
7.625	.375	54	1	15	16	1



# TABLE XXI

DATA FILE DD-963 FOREMAST continued

5.75	.25					
159	.63	71	1	29	30	1
5.75	.25					
\$ SPS55 PLATFORM						
160	.63	22	1	29	30	1
5.75	.25					
161	.63	23	1	29	30	1
5.75	.25					
162	.25	23	1	29	30	1
5.75	.25					
163	.64	23	1	29	30	1
5.75	.25					
164	.64	22	1	29	30	1
5.75	.25					
\$ LOWER YARD AND ERACES						
165	.44	62	1	15	16	1
7.625	.375					
166	.59	62	1	15	16	1
7.625	.375					
167	.49	44	1	31	32	1
11.50	.50					
168	.56	50	1	31	32	1
11.50	.50					
169	.49	55	1	31	32	1
11.50	.50					
170	.50	56	1	31	32	1
11.50	.50					
171	.14	49	1	33	34	1
5.75	.25					
172	.14	50	1	33	34	1
5.75	.25					
*****1*****2*****3*****4*****5*****6*****7***						
\$BLOCK	1	JOINT	CCN	STRAINT	DATA	
\$	JN	IX	IY	IZ	NCJ CARDS	FORMAT 7I10
\$					IXX	IYY IZZ
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	1	1	1	1	1	1
4	1	1	1	1	1	1
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	1	1	1	1	1	1
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	0	0	0	0	0	0
36	0	0	0	0	0	0
37	0	0	0	0	0	0





## TABLE XXII

DATA FILE DD-963 FOREMAST continued

38	0	0	0	0	0	0
39	0	0	0	0	0	0
40	0	0	0	0	0	0
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	0	0	0	0	0	0
47	0	0	0	0	0	0
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	0	0	0	0	0	0
51	0	0	0	0	0	0
52	0	0	0	0	0	0
53	0	0	0	0	0	0
54	0	0	0	0	0	0
55	0	0	0	0	0	0
56	0	0	0	0	0	0
57	0	0	0	0	0	0
58	0	0	0	0	0	0
59	0	0	0	0	0	0
60	0	0	0	0	0	0
61	0	0	0	0	0	0
62	0	0	0	0	0	0
63	0	0	0	0	0	0
64	0	0	0	0	0	0
65	0	0	0	0	0	0
66	0	0	0	0	0	0
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	0	0	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0

\*\*\*\*\*1\*\*\*\*\*2\*\*\*\*\*3\*\*\*\*\*4\*\*\*\*\*5\*\*\*\*\*6\*\*\*\*\*7\*\*\*  
 \$BLOCK J JOINT LEADING DATA 1 CARD FORMAT I10  
 \$ (CMIT IF NLC=C IN BLOCK 8)  
 \$ NLJ  
 \$ 76

JN	FX	FY	FZ	NLJ CARDS	FORMAT	TY	TZ
49	-50.	-100.0	0.0	0.	0.	0.	0.
50	-50.	-100.0	0.0	0.	0.	0.	0.
55	-50.	-100.0	0.0	0.	0.	0.	0.
56	-50.	-100.0	0.0	0.	0.	0.	0.
57	0.	-50.0	0.0	0.	0.	0.	0.

\$ SHIP'S NOTICAL LOADS  
 \$ JN

JN	FX	FY	FZ	TX	TY	TZ
1	0.0	0.0	160.5	0.0	0.0	0.0
2	0.0	0.0	163.3	0.0	0.0	0.0
3	0.0	0.0	136.4	0.0	0.0	0.0
4	0.0	0.0	137.5	0.0	0.0	0.0
5	0.0	0.0	108.2	0.0	0.0	0.0
6	0.0	0.0	184.3	0.0	0.0	0.0
7	0.0	0.0	66.7	0.0	0.0	0.0
8	0.0	0.0	184.3	0.0	0.0	0.0
9	0.0	0.0	414.9	0.0	0.0	0.0
10	0.0	0.0	467.0	0.0	0.0	0.0
11	0.0	0.0	381.6	0.0	0.0	0.0
12	0.0	0.0	381.6	0.0	0.0	0.0
13	0.0	0.0	70.2	0.0	0.0	0.0
14	0.0	0.0	325.4	0.0	0.0	0.0
15	0.0	0.0	325.7	0.0	0.0	0.0
16	0.0	0.0	528.5	0.0	0.0	0.0
17	0.0	0.0	429.1	0.0	0.0	0.0
18	0.0	0.0	226.9	0.0	0.0	0.0
19	0.0	0.0		0.0	0.0	0.0



# TABLE XXIII

DATA FILE DD-963 FOREMAST continued

20	0.0	0.0	214.8	0.0	0.0	0.0
21	0.0	0.0	468.9	0.0	0.0	0.0
22	0.0	0.0	539.0	0.0	0.0	0.0
23	0.0	0.0	539.0	0.0	0.0	0.0
24	0.0	0.0	51.6	0.0	0.0	0.0
25	0.0	0.0	474.7	0.0	0.0	0.0
26	0.0	0.0	2234.2	0.0	0.0	0.0
27	0.0	0.0	2296.2	0.0	0.0	0.0
28	0.0	0.0	1874.0	0.0	0.0	0.0
29	0.0	0.0	1874.0	0.0	0.0	0.0
30	0.0	0.0	1459.2	0.0	0.0	0.0
31	0.0	0.0	1238.5	0.0	0.0	0.0
32	0.0	0.0	1489.9	0.0	0.0	0.0
33	0.0	0.0	211.7	0.0	0.0	0.0
34	0.0	0.0	498.7	0.0	0.0	0.0
35	0.0	0.0	606.8	0.0	0.0	0.0
36	0.0	0.0	498.7	0.0	0.0	0.0
37	0.0	0.0	725.9	0.0	0.0	0.0
38	0.0	0.0	1774.3	0.0	0.0	0.0
39	0.0	0.0	1725.5	0.0	0.0	0.0
40	0.0	0.0	174.3	0.0	0.0	0.0
41	0.0	0.0	345.5	0.0	0.0	0.0
42	0.0	0.0	1729.0	0.0	0.0	0.0
43	0.0	0.0	1729.0	0.0	0.0	0.0
44	0.0	0.0	1425.6	0.0	0.0	0.0
45	0.0	0.0	1810.4	0.0	0.0	0.0
46	0.0	0.0	1468.1	0.0	0.0	0.0
47	0.0	0.0	1810.4	0.0	0.0	0.0
48	0.0	0.0	1468.1	0.0	0.0	0.0
49	0.0	0.0	185.6	0.0	0.0	0.0
50	0.0	0.0	185.6	0.0	0.0	0.0
51	0.0	0.0	540.9	0.0	0.0	0.0
52	0.0	0.0	965.8	0.0	0.0	0.0
53	0.0	0.0	783.4	0.0	0.0	0.0
54	0.0	0.0	464.2	0.0	0.0	0.0
55	0.0	0.0	113.0	0.0	0.0	0.0
56	0.0	0.0	113.0	0.0	0.0	0.0
57	0.0	0.0	254.5	0.0	0.0	0.0
58	0.0	0.0	436.2	0.0	0.0	0.0
59	0.0	0.0	1425.6	0.0	0.0	0.0
60	0.0	0.0	733.8	0.0	0.0	0.0
61	0.0	0.0	304.6	0.0	0.0	0.0
62	0.0	0.0	544.6	0.0	0.0	0.0
63	0.0	0.0	1407.7	0.0	0.0	0.0
64	0.0	0.0	135.0	0.0	0.0	0.0
65	0.0	0.0	138.8	0.0	0.0	0.0
66	0.0	0.0	100.3	0.0	0.0	0.0
67	0.0	0.0	60.1	0.0	0.0	0.0
68	0.0	0.0	60.1	0.0	0.0	0.0
69	0.0	0.0	463.2	0.0	0.0	0.0
70	0.0	0.0	1713.1	0.0	0.0	0.0
71	0.0	0.0	237.0	0.0	0.0	0.0
72	0.0	0.0	1081.2	0.0	0.0	0.0
73	0.0	0.0	1081.2	0.0	0.0	0.0
*****1*****2*****3*****4*****5*****6*****7***						
\$BLCK K FIXED MASS DATA NFMAS CARDS FORMAT I10,F10.0						
\$(CMIT IF NFMAS=C IN BLOCK B)						
\$ JN MASS						
\$ PLATFORM BELCH SPQ-S						
18	0.0					
19	0.0					
20	0.0					
21	0.0					
\$ SPQ-S AND PLATFORM						
26	0.0					
27	0.0					
28	0.0					
29	0.0					
30	0.0					
31	0.0					
\$ SPQ-60 AND PLATFORM						
36	0.0					



```

42          $40.0
43          $40.0
44          $40.0
45          $40.0
46          $40.0
47          $40.0
48          $40.0
49          $40.0
$ SPS-55 AND PLATEFORM
222          225.0
23          325.0
24          325.0
$ ANTENNAS AND OTHER FIXTURES
49          25.0
50          25.0
51          12.0
52          12.0
53          220.0
54          30.0
55          26.0
56          26.0
57          120.0
58          572.0
59          565.0
$*****1*****2*****3*****4*****5*****6*****7***
$BLCK L DESIGN VARIABLE INFORMATION CARDS AS REQ'D FORMAT 8F10.0
$ (AREA AND DIMENSION VARIABLES OMIT IF NDVAR1=0)
$ XA(I) . . . XA(NDVAR1)
$
13.75      .75      7.625      .375      8.625      .375      7.625      .375
3.625      .375      12.50      .50      7.625      .375      7.625      .375
7.625      .375      23.00      1.50      9.50      .50      14.00      .75
10.00      .50      7.625      .375      7.625      .375      11.50      .50
5.75      .25
$ XAL(I)
$
8.00      .50      5.000      .250      5.000      .250      5.000      .250
5.000      .250      8.00      .250      5.000      .250      5.000      .250
5.000      .250      15.00      .50      6.00      .25      10.00      .50
6.00      .25      5.000      .250      3.00      .10      8.00      .25
3.00      .10
$ XAU(I)
$
22.00      2.50      15.00      1.50      15.00      1.50      15.00      1.50
15.00      1.50      22.00      2.50      15.00      1.50      15.00      1.50
15.00      1.50      36.00      2.50      15.00      1.50      26.00      2.00
12.00      1.50      15.00      1.50      12.00      1.50      22.00      1.50
1.50
$*****1*****2*****3*****4*****5*****6*****7***
$BLCK N JOINT DISPLACEMENT CONSTRAINTS NDSPLC CARDS FORMAT 3I10,2F10
$ (OMIT IF NDSPLC=C IN BLOCK 8)
$ JN      CIR      LC      BL      BU
$
67          1          1          1          1
67          1          1          1          1
46          1          1          1          1
48          1          1          1          1
22          1          1          1          1
22          1          1          1          1
23          1          1          1          1
23          1          1          1          1
64          1          1          1          1
31          1          1          1          1
1          1          1          1          1
$*****1*****2*****3*****4*****5*****6*****7***
$BLCK C FREQUENCY CONSTRAINTS
$
2.0
$*****1*****2*****3*****4*****5*****6*****7***
$ELCK P END CARD
END

```



## APPENDIX B

### PROGRAM ORGANIZATION

#### A. DESCRIPTION

The program organization is layed out in the following flow charts. The main driver program (SADXM) calls a subdriver (SADXSD), and the optimizer of the user's choice. All changes required for replacement of the optimizer are made in SADXM, thus allowing for easy testing of several optimizers on the same problem.

SADXSD may be called from the main for input, analysis, and output. Printed output may vary as the user requires. A complete listing of all subroutines and their functions is given in Table XXIV.





# TABLE XXIV

## SUBROUTINE DIRECTORY

SADXM-----	DRIVER PROGRAM FOR USING THE ABOVE SUBROUTINES. SADXM MAY BE COUPLED TO OPTIMIZER OF USER'S CHOICE.
SADXSD	SUBDRIVER PROGRAM FOR COUPLING SADX ROUTINES TO SADXM
SADX01	THIS ROUTINE READS AND PRINTS INPUT DATA AND ORGANIZES PSEUDO-DYNAMIC STORAGE ALLOCATION
SADX02	BUILDS VECTORS JC AND IJK FOR FINITE ELEMENT STRUCTURAL ANALYSIS
SADX03	BUILDS THE 12x12 ELEMENT STIFFNESS MATRIX
SADX05	SUPERIMPOSES THE ELEMENT STIFFNESS MATRIX EK (OR ELEMENT MASS MATRIX EM) ON THE COMPACTED GLOBAL STIFFNESS MATRIX AK (OR THE GLOBAL COMPACTED MASS MATRIX AM)
SADX06	BUILDS GLOBAL LUMPED MASS MATRIX
SADX07	LU DECOMPOSES SYMMETRIC POSITIVE-DEFINITE SPARCE MATRICES, THE UPPER TRIANGLE OF WHICH IS STORED IN MATRIX AK (OR AM) WITH LEADING ZEROES NOT STORED
SADX08	FORWARD AND BACK SUBSTITUTES TO YIELD A SOLUTION A SET OF LINEAR EQUATIONS (DECOMPOSED BY SADX07 OR EQUIVALENT)
SADX09	PRINTS ALL JOINT DISPLACEMENTS FOR EACH LOAD CONDITION OF A FINITE ELEM. STRUCTURE
SADX11	ROUTINE TO ORGANIZE ANALYSIS
SADX15	CALCULATES VALUES FOR ALL DESIGN AND BEHAVIORIAL CONSTRAINTS AS DEFINED BY "SADX" PROGRAM
SADX16	CALCULATES STRESS IN TRUSS ELEMENT LNO UNDER LOAD CONDITION JJ
SADX17	PRINTS STRESSES AND/OR FORCES FOR TRUSS ELEMENTS
SADX19	ADDS ELEMENT MASS MATRIX AA OF ELEMENT LNO TO GLOBAL MASS MATRIX AM TO BUILD THE LUMPED MASS MATRIX
SADX23	CALCULATES WEIGHT OF TRUSS/FRAME STRUCTURE OR CALCULATE WEIGHT OF INDIVIDUAL MEMBERS
SADX36	CALCULATES (XEIG-T*AM*XEIG) FOR GRADIENT CALCULATIONS IN FREQUENCY CONSTRAINTS
SADX37	CALCULATES EIGENVALUE GRADIENT INFORMATION IN FINITE ELEMENT STRUCTURAL ANALYSIS AND DESIGN



SADX46        READS INPUT INFORMATION FOR TRUSS  
ELEMENTS

SADX47        TRANSFORMS THE ELEMENT STIFFNESS MATRIX  
EK (OR ELEMENT MASS MATRIX EM) FROM LOCAL  
TO GLOBAL COORDINATES

SADX49        SOLVES REAL EIGENVALUE PROBLEMS USING  
THE SUBSPACE ITERATION METHOD

SADX50        BUILDS INITIAL SET OF BASIS VECTORS  
FOR EIGENSOLUTION BY REDUCED BASIS  
METHOD

SADX53        PRINTS MEMBER INFORMATION FOR TRUSS  
ELEMENTS

SADX62        PRINTS NEIG EIGENVALUES STORED IN  
EIGVAL, AND THEIR CORRESPONDING  
EIGENVECTORS STORED IN XEIG

SADX71        PRINTS G VECTOR OF CONSTRAINTS

SADX72        READS IN FRAME ELEMENT INPUT DATA

SADX78        BUILDS 3x3 TRANSFORMATION ARRAY PRFORM  
FOR TRANSFORMING FROM LOCAL TO GLOBAL  
COORDINATES

SADX80        CALLS SADX03 TO BUILD THE ELEMENT STIFFNESS  
MATRIX; CALLS SADX47 TO TRANSFORM THE MATRIX;  
AND CALLS SADX05 TO BUILD THE REDUCED GLOBAL  
STIFFNESS MATRIX

SADX81        CALCULATES STRESS IN FRAME ELEMENT LNO UNDER  
LOAD CONDITION JJ (IF JJ=0 STRESSES CALCUL-  
ATED FOR ALL LOAD CONDITIONS)

SADX82        READS INPUT DATA FOR FRAME ELEMENTS WITH  
SPECIFIED SECTION TYPES

SADX83        PRINTS STRESSES AND/OR FORCES FOR FRAME  
ELEMENTS

SADX84        PRINTS MEMBER INFORMATION FOR FRAME ELEMENTS

SADX85        CALCULATES SECTION PROPERTIES FOR FRAME  
ELEMENTS OF A SECTION TYPE GIVEN BY LSECT

SADX86        CALLS EITHER SADX06 TO BUILD THE LUMPED MASS  
MATRIX OR BUILDS THE CONSISTENT MASS MATRIX  
BY CALLING SADX87 TO BUILD THE ELEMENT MASS  
MATRIX, SADX78 TO BUILD THE TRANSFORMATION  
MATRIX, SADX47 TO TRANSFORM THE ELEMENT MASS  
MATRIX, AND SADX88 TO ASSEMBLE THE COMPACTED  
GLOBAL MASS MATRIX

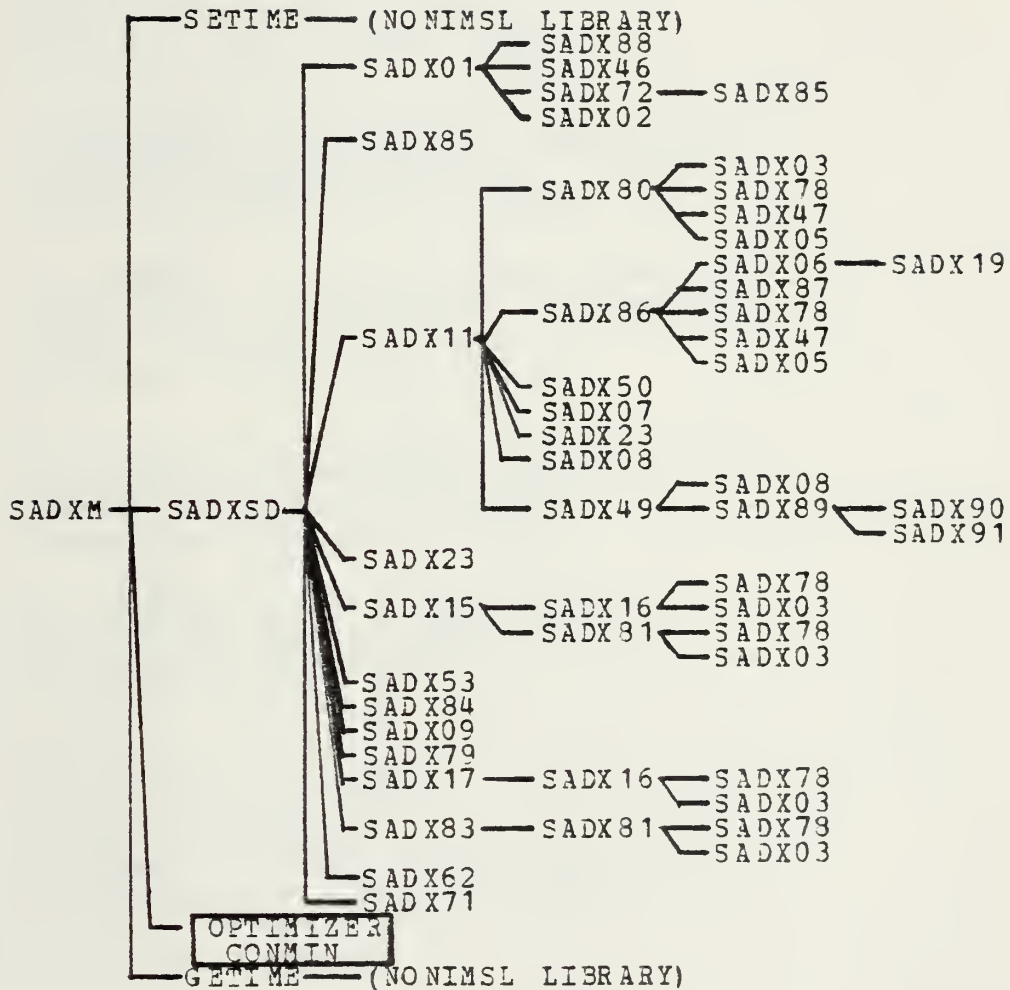
SADX87        CALLS BUILDS THE ELEMENT CONSISTENT MASS  
MATRIX



SADX88	CONVERTS UNFORMATTED DATA TO FORMATTED DATA IN FIELDS OF 10, EACH RIGHT JUSTIFIED AND ACCEPTS \$COMMENT CARDS IN DATA
SADX89	SOLVES EIGENVALUE PROBLEM $ A - \lambda B  X = 0$
SADX90	SOLVES EIGENVALUE PROBLEM
SADX91	SOLVES EIGENVALUE PROBLEM
SETIME	STARTS EXECUTION TIMER (NONIMSL LIBRARY)
GETIME	STOPS EXECUTION TIMER (NONIMSL LIBRARY)



TABLE XXV  
PROGRAM BLOCK DIAGRAM







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Thesis  
B36625 Bender  
c.1

198674

Optimization of  
three dimensional  
combined truss/frame  
structures.

75

198674

Thesis  
B36625 Bender  
c.1

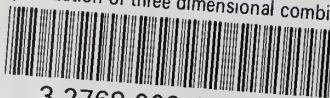
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Optimization of  
three dimensional  
combined truss/frame  
structures.



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Optimization of three dimensional combin



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